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SEED FILLING AND OIL ACCUMULATION IN NOUG [*GUIZOTIA ABYSSINICA* (L.F.) CASS.]

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ABSTRACT: A field experiment was carried out to study the pattern, rate and duration of seed dry weight (SDW) and oil accumulation in two improved noug varieties during 1995 and 1996. Seeds from uniformly flowered heads were harvested manually seven days after anthesis initiation (DAAI) and continued for 60 days with four days interval. Thousand seed weight and percent oil content were determined for each harvest. The study shows that the extended reproductive period in noug could be well shortened by selecting plants with determinate or semi-determinate growth habit without affecting seed and oil yield. Plants with determinate or semi-determinate growth habit are, hence, morphological ideotypes to look for in noug improvement.

Key words/phrases: *Guizotia abyssinica*, oil accumulation, noug, seed dry weight accumulation

INTRODUCTION

Noug [*Guizotia abyssinica* (L.F.) Cass.] is the most important oil crop in Ethiopian agriculture. It is cultivated in almost all parts of the country for its prestigious edible oil. As noug is less important in other parts of the world, studies on basic and applied aspects of the crop are scanty. Hence lack of scientific information is the major shortcoming in our noug improvement endeavour.

Although plant storage organs are known to accumulate protein, starch and/or oil, considerable variations among plant species exists in partitioning these storage compounds. Starch is the main storage product in cereals while both protein and starch are found in legumes. In oilseeds, however, lipids are the principal storage compounds with smaller amount of protein (Morgan and Rawsthorne, 1995).

As an oil crop, the ultimate goal of noug production is to attain increased oil yield per unit of area, which is a function of seed yield and oil content. Thus, these two characters deserve considerable attention in noug research.

Oil content is largely a characteristic of a species but is reported to be influenced by environmental factors such as mean daily temperature and availability of moisture especially during seed filling (Canvin, 1965). In reviewing the environmental factors that regulate oil content in rapeseed, Robblen and Thies (1980) indicated temperature to be one of the most important factors. They also reported that various plant nutrients influence the oil content of rapeseed. Nitrogen dressing caused depression in oil content. On the other hand, phosphorous in combination with potassium increased the oil content, possibly by favouring metabolic activities in the formation and transformation of carbohydrate into fat. Similarly, manganese fertilization was effective in increasing or at least maintaining the oil content.

Rate and duration of grain filling is extensively studied in grain crops like maize (Dynard *et al.*, 1971; Johanson and Tanner, 1972) and in some oil crops like Soya bean (Egli *et al.*, 1978; Sales and Campbell, 1980; 1982), sunflower (Anderson, 1975; Mundstock and Mundstock, 1988; Rana *et al.*, 1992) and rapeseed (Robblen and Thies, 1980). Consequently, it has been observed that factors influencing either the rate or duration will have a direct influence on yield (Egli *et al.*, 1978; Mundstock and Mundstock, 1988).

In sunflower Maeda *et al.* (1987) found that seed oil content increased from 2.2% to 46.6% 10 days after flower initiation to 30 days after flowering, respectively. Samui *et al.* (1980) reported that 1000 seed weight, protein and oil content in sunflower increased between 95–119 days after sowing. Singh *et al.* (1988) observed that oil accumulation in sunflower reach the highest 33 days after anthesis initiation. In rapeseed Robblen and Thies (1980) reviewed the rate of oil synthesis and deposition during seed development and showed that it generally follows a sigmoid curve. It showed a sharp rise in the middle third of the grain development period *i.e.*, 20 to 40 days after flowering when seed ripens at about 55 days after flowering. Much less change in oil content was registered during the later stage up to maturity; in few cases, even with some decrease in oil content with further increase in seed weight.

Noug is characterized by indeterminate growth habit (Weiss, 1983; Hiruy Belayneh, 1987; Riley and Hiruy Belayneh, 1989; Getinet and Sharma, 1996). At field condition, noug heads flower over an extended period of 4–6 weeks (Riley and Hiruy Belayneh, 1989). Ripe buds and young flowers may be present on the same plant at harvest which result in uneven ripening that cause loss from seed shattering (Hiruy Belayneh, 1987). In Ethiopia noug flowers within 50–100 and matures 150–180 days after planting (Riley and Hiruy Belayneh, 1989). This brings the reproductive duration to about 80–100 days. This period, however, need not be taken as an effective seed dry weight (SDW) and oil accumulation period for all flowers (late and early formed) as there is a wide gap in flower initiation within a plant. Hence, characterizing the seed developmental dynamics with respect to the rate and duration of seed dry weight and oil accumulation within this extended reproductive period is important.

The present study, therefore, is a contribution for understanding the pattern, rate and duration of SDW and oil accumulation in noug. The information is thought to be useful in establishing a base line for future investigation concerning the rate and total accumulation of SDW and oil of the seed in breeding noug genotypes with determinate growth habit and other physiological studies. It has also a practical application in management decisions such as determining harvesting time and the need of supplement irrigation and plant protection measures.

MATERIALS AND METHODS

The experiment was conducted at Holetta Research Center (Kuyu), Ethiopia (2400 m.a.s.l, 09° 03'N and 38° 30'E) during the main season of 1995 and 1996. The experimental site is characterized by a dark grey-clay soil (pellic-eutric vertisol). Meterological data recorded during the study period is shown in Table 1.

Two released varieties namely, "Fogera" and "Kuyu" were included in the study. Kuyu has higher yield and flowers and matures earlier than Fogera. The experiment was laid out as a split-plot design with two replications. Sixteen harvesting stage treatments were compared. Varieties were assigned to main plots and harvesting stages (DAAI) to sub-plots. Totally the experiment included 64 plots (two varieties, two replications and 16 harvest dates).

Individual sub-plots consisted six rows spaced 30 cm apart and 5 m long. Planting was done on June 22 and June 21 in 1995 and 1996, respectively. Seed rate was 10 kg/ha. Fertilizer was applied at each plot at a rate of 23/23 kg/ha of N and P_2O_5 at planting. Two hand weedings, the first three weeks after planting and the second 2 months after planting, were carried out.

Table 1. Metereological data recorded during the study period.

Month	Rainfall (mm)		Average daily temperature (^{0}c)						Relative humidity (%)		Total sunshine hours	
			Minimum		Maximum		Mean					
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
April	123.8	58.4	9.8	7.4	22.5	23.2	16.2	15.3	66	56	145.8	192.6
May	81.3	55.4	7.6	7.3	23.9	23.5	15.9	15.4	56	56	235.5	185.5
June	91.6	183.8	6.5	8.2	23.6	20.6	15.1	14.4	63	74	197.1	119.3
July	197.1	249.8	8.6	8.6	19.4	19.8	13.9	14.3	79	78	83.2	98.9
August	262.7	226.6	8.8	8.3	19.6	19.4	14.7	13.8	81	79	93.5	88.0
September	82.1	120.7	6.3	7.1	20.6	20.4	13.4	13.7	73	74	136.1	132.2
October	15.5	5.3	3.4	3.2	22.6	22.4	12.6	12.7	52	48	254.2	267.0
November	0	1.4	1.7	2.5	23.4	22.5	12.5	14.4	46	46	287.6	253.5
December	34.0	2.3	3.3	1.6	22.8	22.6	13.1	12.1	48	42	273.4	283.6
Total	888.1	903.7	6.2	6.0	22.0	21.6	14.2	13.8	62.7	61.4	1706.4	1620.6

The different harvesting date treatments were created as follow. Large number of uniformly flowered heads (date of ray floret opening written on the label) from 30–35 randomly selected plants were tagged on the day when the ray floret, the most outer flower whorl, started to open. Leaving the outer three whorls of florets, the central florets in each head were removed by forceps since florets on the inner whorl of each heads are late in anthesis and dehiscence. After all the florets in each head completed anthesis, tagged heads were covered with crossing bag (glassine paper) to protect them from bird damage and seed shattering. The tagged heads prepared for the observation were first harvested seven DAAI of the ray floret, then 15 other harvests were carried every four days.

The heads harvested at specific DAAI were threshed and oven dried at 78°C for 48 h. Seed from each harvest were counted to determine 1000 seed weight. Two gram of seed was used to determine the oil content using Nuclear Magnetic Resonance (NMR) Spectrometer within two days after harvesting. The absolute oil content (AOC) per 1000 seeds was calculated from the 1000 seeds weight and the percent oil content (POC) recorded at a particular harvesting stage as AOC (g) = 1000 seed weight (g) × POC.

Rate of dry matter and oil accumulation was calculated as a linear coefficient of regression of SDW, POC and AOC on time, by pooling their mean over year, replication and harvesting stages. The average rate of SDW and oil accumulation during the major phase of seed growth was estimated and the slower rates of growth during early and late SDW and oil accumulation period were ignored (Johnson and Tanner, 1972). Then the effective duration (linear increment phase) of SDW and oil accumulation was estimated following Daynard *et al.* (1971) as the quotient of AOC, POC and 1000 seed weight and their respective rate of growth.

RESULTS

Analysis of variance

Analysis of variance showed that seed weight and oil content (absolute and percent values) did not significantly differ with year (Table 2). However, there was a significant difference between varieties for SDW and AOC ($P < 0.05$). Similarly, variations due to harvesting time for the three parameters (SDW, POC and AOC) measured and interaction effects for POC (year × harvesting date, variety × harvesting date and year × variety × harvesting date) were statistically significant (Table 2).

Table 2. Analysis of variance.

Source of variation	DF	Mean Square		
		SDW	AOC	POC
Year (Y)	1	0.153	0.051	10.058
Replication	1	0.010	0.000	2.311
Variety (V)	1	1.262*	0.301*	12.251
Y × V	1	0.386	0.062	1.256
Error	2	0.037	0.000	1.594
Harvesting date (HD)	15	9.168**	2.235**	1388.087**
Y × HD	15	0.055	0.006	4.891**
V × HD	15	0.053	0.014	7.821**
Y × V × HD	15	0.065	0.010	8.972**
Error	62	0.051	0.007	1.951
CV (%)		8.79	9.18	4.44

DF, Degrees of freedom *, Significant at $P < 0.01$ probability level; **, Significant at $P < 0.001$ probability level; SDW, seed dry weight; AOC, absolute oil content; and POC, percent oil content

Rate and duration of SDW and oil accumulation

Variability in seed weight accumulation of the two varieties as affected by the different harvesting time is presented in Fig. 1. The mean SDW accumulation rate/1000 seeds/day was 91.83 mg for Fogera and 93.55 mg for Kuyu (Table 3). The highest amount of SDW was attained at 51 DAAI in both varieties. The effective duration of SDW accumulation was calculated to be 37.24 days for Fogera and 38.38 days for Kuyu.

Similar to the seed weight, Kuyu exhibited a higher rate and duration of oil accumulation (AOC and POC) than Fogera (Fig. 2). Values for rate of oil accumulation (AOC) were 62.80 and 64.80 mg/1000 seeds/day while their duration were 21.61 and 22.61 days for Fogera and Kuyu, respectively. POC increased at a rate of 1.75 percent/day for Fogera and 1.99 percent/day for Kuyu; the effective duration of accumulation was 23.47 days for Fogera and 21.30 days for Kuyu (Table 3).

Mean duration of effective SDW accumulation period was longer (37.87 days) than the duration of oil accumulation (21.69 days for AOC and 22.32 for POC) (Table 3).

Quite similar to other crop seeds, noug seed did not grow at a constant rate, but rather has a lag period at its early stage of development (up to 11 DAAI) followed by an active growing period (from 12 to 31 DAAI) and then a plateau (Figs 1 and 2). Just seven DAAI, oil was less than 3.26 percent of the total seed weight of the seed. This value increased to 5.70 at the 11th DAAI, but it represents only 3.25 percent of the total oil accumulated in the mature seed. By comparison, during the same period 18.11 percent of the total seed weight had already been formed. From 15 to 35 DAAI the oil accumulation percent increased from 11.68 to 40.06 percent while the SDW increased from 1.139 g to 2.841 g/1000 seed weight. A linear increase in both SDW and oil was observed here. Between 35 and 51 DAAI, increase in seed weight was higher than the increase in oil content. About 9.13 percent of the total seed weight and 7.66 percent of the total oil of the matured seed were synthesized during this period.

Table 3. Rate and duration of SDW and oil accumulation in noug.

Genotype	Rate of accumulation	Mean maximum accumulation	Effective duration (days)	Student's t-value	Significance of regression	Coefficient of determination (R^2)
			SDW (/1000 seed/day)			
Fogera	91.83 mg	3.42 (3.08) g	37.24 (33.54)	20.830	0.000	0.935
Kuyu	93.55 mg	3.60 (3.23) g	38.38 (34.53)	15.257	0.000	0.886
Mean*	92.69 mg	3.51 (3.16) g	37.87 (34.09)	24.093	0.000	0.903
			AOC (/1000 seed/day)			
Fogera	62.80 mg	1.36 (1.221) g	21.61 (19.44)	8.681	0.000	0.843
Kuyu	64.80 mg	1.49 (1.321) g	22.65 (20.38)	13.510	0.000	0.929
Mean*	63.80 mg	1.38 (1.246) g	21.69 (19.53)	13.918	0.000	0.866
			POC			
Fogera	1.75 %	41.08 (36.97) %	23.47 (21.13)	15.620	0.000	0.931
Kuyu	1.99 %	42.38 (38.14) %	21.30 (19.17)	15.175	0.000	0.927
Mean*	1.89 %	41.73 (37.56) %	22.32 (20.09)	21.611	0.000	0.925

Values in parenthesis show 90 % of the maximum SDW, AOC and POC that were used to calculate the respective rates and duration.
* Means obtained by pooling the original observations over replication, year, variety and harvesting stage.

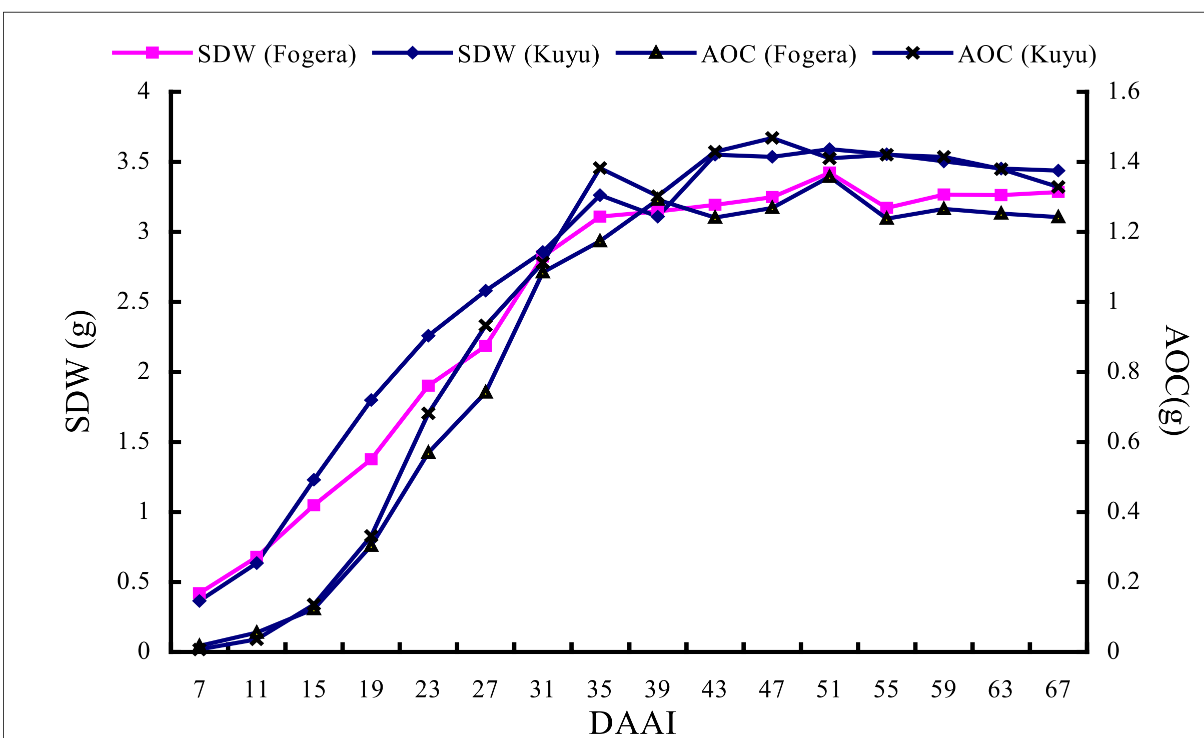

Fig. 1. SDW and AOC as affected by harvesting seeds at different DAAI.

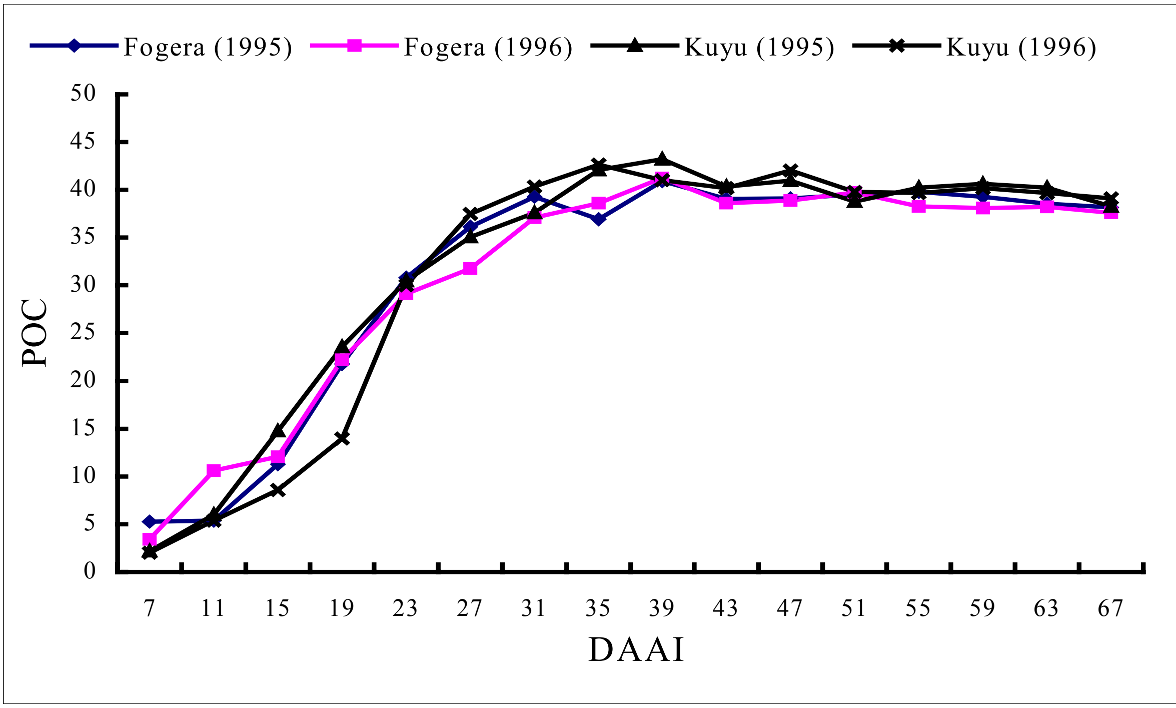

Fig. 2. POC **as affected by year, variety and harvesting seeds at different** DAAI.

Associations among DAAI, SDW, AOC and POC

The association among DAAI, SDW, AOC and POC is presented in Table 4. A positive association did exist between DAAI and SDW (r = 0.872), AOC (r = 0.867) and POC (r = 0.799). SDW was positively correlated with AOC (r = 0.985) and POC (r = 0.928). AOC and POC were also positively associated (r = 0.950).

Table 4. Relationship between DAAI and seed characters as determined by correlation analysis.

Characters	Correlation coefficients	Students' t-value	Standard error
DAAI vs SDW	0.872***	19.966	0.003
DAAI vs AOC	0.867***	19.552	0.001
DAAI vs POC	0.799***	14.923	0.037
SDW vs POC	0.928***	30.174	0.376
SDW vs AOC	0.985***	63.526	0.008
AOC vs POC	0.95***	34.162	0.001

***, Significant at P < 0.0001 probability level; DAAI., days after anthesis initiation; SDW, seed weight; AOC, absolute oil content; and POC, percent oil content.

DISCUSSION

The analysis of variance indicated that the two varieties included differed in SDW and AOC. The mean rate of SDW accumulation was higher for Kuyu (93.55 mg/100/day) than Fogera (91.83 mg/100/day). Closer observation to the pattern of SDW accumulation reveals that, Kuyu exhibited higher rate of SDW accumulation between 11 and 31 DAAI. As it can be seen from Fig. 1, this period coincides with the linear rate of increase in seed weight, which ultimately gave Kuyu a higher mean SDW accumulation rate. Before and after this period, the rate of SDW accumulation was essentially the same for the two varieties (Fig. 1). In sunflower, mean seed dry weight gain varied from 14 to 21 mg/100 seeds/day (Mundstock and Mundstock, 1988). Besides having higher rate SDW accumulation, Kuyu exhibited a longer duration of SDW than Fogera. This shows that variation between the two tested varieties for SDW is a result of both rate and duration of SDW accumulation. However, Mundstock and Mundstock (1988) observed that, with few exceptions the longer the duration of sunflower achene filling period, the lower the filling rate would be.

Mean SDW, AOC and POC were similar with in years (1995 and 1996). This indicates that variation in meteorological factors during the two years were not sufficient to produce variation in SDW, AOC and POC.

The sixteen harvesting stage treatments were statistically different with respect to SDW, AOC and POC. The earlier stage of seed development of noug, from anthesis initiation to 11 DAAI, is characterized by slow rate of SDW and oil accumulation. During this period, only 18.11 percent of the total seed weight had been formed. During the same period, there was very little oil accumulated, only 5.7 percent of the total oil content. Similarly, low rates of fat depositions during the early period of seed development have also been reported in other oil seeds (Anderson, 1975; Yazadi-samadi, 1977). A 3.5 POC was recorded in Soya bean seed ten days after flowering (Yazadi-samadi, 1977) and a 3.0 POC in sunflower four DAAI (Anderson, 1975).

A linear increase in both SDW and oil was observed during 15 to 35 DAAI, but the rate of increase was higher for oil than SDW. During this period about 89.09 percent of the oil and 72.76 percent of the final seed weight was accumulated. This indicates that increase in total seed weight is largely attributed to increase in oil concentration. At the same time accumulation of other constituents of the seed were lower than the oil. This period, therefore, coincides with the critical stage of seed development to both oil and seed weight accumulation. Growth resources limitation or other adverse growing conditions at this stage will result in seed and oil yields penalty. Hence, there is a need to optimize agronomic intervention during this period.

In the later stage of seed development, between 35 and 51 DAAI, a lower rate of SDW and oil accumulation was recorded. During this period increase in seed weight (9.13 percent) was higher than the increase in oil content (7.66 percent). This shows that, the contribution of oil for the increase in total seed weight was rather low as compared to other seed constituents.

After attaining their peak, SDW, AOC and POC showed a slight decline rather than remaining constant until harvest (Figs 1 and 2). Loss of seed weight is at large related to loss of oil than other constituents of the seed. About 67 percent of the total seed weight loss is attributed to oil loss. According to this study, late harvesting is discouraged for loss of SDW and oil of the seed. Hiruy Belayneh (1987) observed a loss in oil content in noug, although was not consistent across years. Anderson (1975) observed reduction of oil at senescence in sunflower. In seed of soya bean a significant oil loss occurred during late pod filling. The magnitude of oil loss was measured to be 9 to 14 percent of the maximum oil content of the seed (Sales and Campbell, 1980; 1982). According to Howell *et al.* (1959), seed respiration could explain most of the oil loss during late senescence. Hocking and Mason (1993), reported redistribution of nutrients such as Nitrogen and Phosphorous from pods to developing seeds during senescence in rapeseed especially in situation where plant uptake of key nutrients ceases during seed filling because of low soil moisture. For indeterminate crops like noug, probably mobilization of storage products from early formed to lately formed seeds and flowers due to shortage of photosynthate during plant maturity could be another reason for the oil and weight loss of the seed. Therefore breeding for determinate or semi-determinate type of noug is substantiated by this result to be of prime importance in noug improvement.

From this study it appeared that, the maximum POC does not necessarily indicate the maximum oil weight (Figs 1 and 2). The maximum POC was attained 39 DAAI, whereas the maximum AOC was attained later, at 51 DAAI. About 3.69 percent of the total oil in the mature seed was accumulated after the POC reached its peak. Since synthesis of oil was accomplished at a slower rate than synthesis of other constituents of the seed, oil accumulated after 39 DAAI was not reflected by increase in POC. This is because percent oil expresses the proportion of oil to other seed constituents than indicating the total content of oil in the seed. In sunflower, Rana *et al.* (1992) reported that oil accumulation reaches its peak on the 30 and 34 DAAI, while Anderson (1975) observed maximum oil accumulation at 35 DAAI, the duration to reach peak varying on seasons.

The correlation analysis showed the type and extent of association among DAAI, SDW, AOC and POC. A positive association has been observed between DAAI and SDW (r = 0.872), AOC (r = 0.867) and POC (r = 0.799) suggesting that longer period of grain filling favour the total amount of SDW and oil content in noug seed. SDW was positively correlated with AOC (r = 0.985) and POC (r = 0.928).

This indicates that an increase in seed weight is associated with increase in seed oil content or the vice versa. AOC and POC were also positively associated (r = 0.950). This relationship is expected, as POC is the relative expression of absolute oil weight in the seed.

CONCLUSION AND RECOMMENDATION

The experiment demonstrated that the actual duration of SDW and oil accumulation is short as compared to the reproductive period of the crop, 80–100 days. Actually, the effective mean duration of SDW accumulation is 39 days while that of oil accumulation is 22 days (Table 3). This also shows that the maximum oil content is attained earlier than the maximum oil and seed weight. Hence, the percent value for oil can be determined at a fairly early stage of development than the absolute oil and seed weight values. Generally, in rapid generation enhancement of noug breeding works, specific head base harvesting could be done at about 39 DAAI. By this analogy, in selecting determinate type of noug plants, the reproductive duration can well be shortened without affecting the seed and oil yield. The variation observed between the two varieties for rate and duration of SDW and oil accumulation can be used as selection criterion towards identifying genotypes with improved seed and oil yield.

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