USE OF CARBON ISOTOPE DISCRIMINATION TO INDIRECTLY SELECT FOR IMPROVED SEED YIELD IN LENTIL

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ABSTRACT
Carbon isotope discrimination (CID) has been proposed as a secondary trait to indirectly select for improved water use efficiency and seed yield. To determine the effectiveness of CID to indirectly select for seed yield, ten diverse lentil (*Lens culinaris* Medikus) cultivars were grown at four locations in Saskatchewan in 1992 and 1993. Variability for CID was present among these lentil cultivars and no crossover interactions were observed. The phenotypic correlation between seed yield and CID of leaves at early flowering (CIDLF) was 0.82** (df=8). However, this highly significant relationship resulted from the extreme early maturity of PI 244026. Previous research has shown that CID values decrease with maturity and PI 244026 flowers about 15 days earlier than the other lentil lines. When PI 244026 lentil was removed, variability in CID was greatly reduced and the correlation between CIDLF and seed yield approached zero (r = 0.22, df=7). These results suggest that CIDLF cannot be used to indirectly select for seed yield in lentil.

INTRODUCTION
Carbon isotope discrimination (CID) has been proposed as a secondary trait to indirectly select for WUE and seed yield in several crops (Farquhar and Richards, 1984; Hubick et al., 1986; Condon et al., 1987). According to theory, as discrimination against ^{13}C decreases WUE increases at the leaf level (Farquhar et al., 1982). The relationship is not direct. CID and WUE are linked through the intercellular partial pressure of CO_2 (P_i). P_i is directly related to CID and inversely related to WUE. However, at the plant level, the negative correlation between CID and WUE does not hold for all water regimes (Farquhar and Richards, 1984) or all populations of cultivars within a crop (Ehleringer, et al., 1991).

If the negative correlation between CID and WUE at the plant level is maintained at the crop level, selecting for low CID values will increase crop WUE, then both total dry matter (TDM) and seed yield should increase unless harvest index is reduced. That is, CID should be negatively correlated with both TDM and seed yield, suggesting that CID could be used to indirectly select for TDM and seed yield.

The effectiveness of CID as a secondary trait to indirectly select for improved seed yield in lentil will depend on the variability for CID among cultivars, the magnitude of the genotype by environment (G * E) interaction for CID, and the magnitude of the correlation between CID and seed yield (Blum, 1983). Therefore, the objectives of this study were to: screen lentil cultivars for differences in CID of leaves at flowering (CIDLF); determine the magnitude of the cultivar by environment interaction for CIDLF; and determine the magnitude of the correlation between CIDLF and seed yield.

MATERIALS AND METHODS
Ten lentil lines (Table 1), chosen to represent a wide range of morphological and phenological characteristics, were grown at four locations in Saskatchewan in 1992 and 1993. Locations were: Hagen (silt loam), Goodale farm (sandy loam), Sutherland farm (clay loam) and Outlook (sandy loam). The experimental design was a RCBD with four replications. Data were collected for CID of leaves at flowering (CIDLF) when approximately 80% of the lentil lines were in flower. The isotopic composition was

determined according to the methodology described by Knight et al. (1994). CID was calculated assuming an isotopic composition of the air of -8 ‰ (Farquhar and Richards, 1984), relative to PDB. Seed yield was determined at harvest.

The Azallini and Cox test for crossover interaction was used to determine change in ranking for CID of lentil cultivars among locations and years (Baker, 1988).

RESULTS

Lentil cultivars differed significantly in CIDLF (Table 1). The C * L interaction was not significant for any of those traits. A significant C * L non crossover interaction was observed for CIDLF caused by changes in the magnitude of the response of Precoz and Indianhead lentil. Thus, the ranking of lentil cultivars for CIDLF remained constant across years.

Seed yield was significantly and positively correlated with CIDLF (r = 0.82**, df = 8).

Table 1. Means for grain yield and carbon isotope discrimination of leaves at flowering (CIDLF) for ten lentil cultivars grown in Saskatchewan at four locations in 1992 and 1993.

Cultivar	**Grain yield ($t\ ha^{-1}$)**	**CIDLF (10^3 †)**
Eston	3.19	21.13
Laird	2.58	20.80
CDC Richlea	3.13	20.78
PI 244026	1.32	19.78
Indianhead	2.57	21.15
Emerald	2.84	21.13
Du Puys	3.40	21.17
Chilean	2.75	21.36
Precoz	2.70	20.73
Pardina	3.12	21.21
Mean	2.76	20.93
CV (%)	12	2.76
Standard error	0.07	0.14
LSD (0.05)		0.35

Source	DF	Mean Squares			
Years (Y)	1	14.93		128.26	**
Locations (L)	3	58.60		2.34	
Y * L	3	28.83	**	4.27	**
Replications (Y L)	24	0.24	**	0.58	**
Cultivars (C)	9	10.73		6.58	**
C * L	27	0.70		0.25	
C * Y	9	0.24		0.57	*
C * Y * L	27	0.78	**	0.23	
Error	216	0.16		0.59	

† Actual number was multiplied by this to get the reported number
*, ** Significant at the 0.05 and 0.01 level, respectively.

DISCUSSION

Lentil cultivars differed significantly in CIDLF (Table 1). The range for CIDLF was 1.58 ‰. Variability in CID may be caused by differences in stomatal conductance or photosynthetic capacity among cultivars (Condon et al., 1992b). However, cultivar differences in phenology, root depth (White et al., 1990), plant vigour (Virgona et al., 1990; Condon et al., 1992a) or photorespiration (Rooney, 1988), as well as differences in leaf to air vapour pressure (Condon et al., 1992b) may induce variation in CID at the crop level. In the present experiment differences in CIDLF among lentil cultivars were probably due to differences in days to flower. PI 244026 flowers extremely early in comparison with the other lentil cultivars. When sampling at 80% flowering, PI 244026 was already in mid-podding. Previous research has shown that CID decrease with maturity (Condon and Richards, 1992). The range of CID became smaller when PI 244026 was removed from the analysis. Variation in CID has been reported in common bean (*Phaseolus vulgaris* L.) (Ehleringer et al., 1990), cowpea (*Vigna ungiculata* L) (Hall et al., 1990), and peanut (*Arachis hypogaea* L.) (Hubick et al., 1986, 1988). The significant year by cultivar interaction for CIDLF observed in the present experiment was not a crossover interaction. Therefore, the ranking of lentil cultivars for CIDLF remained constant across years. The significant interaction was caused by changes in the magnitude of the response for CIDLF of Precoz and Indianhead lentil from year to year. In both years Indianhead had higher CIDLF than Precoz lentil. Significant G * E interaction for CID was reported for common bean (White et al. 1990) and cowpea (Hall et al., 1990), but not for peanut (Hubick et al., 1988; Wright et al., 1988).

The highly significant positive correlation between seed yield and CIDLF resulted from the extreme early flowering of PI 244026. Previous research (Condon and Richards, 1992) has shown that CID values decrease with maturity and PI 244026 flowered about 15 days earlier than the other lentil lines. When PI 244026 was removed from the analysis, the correlation approached zero. These results suggest that CID cannot be used to indirectly select for seed yield in lentil. Similarly, early maturing wheat cultivars had low CID and low seed yield (Condon and Richards, 1992). They suggested that, in order to improve WUE or seed yield by selecting for low CID in Australian wheat, cultivars with low CID and high seed yield must be found. According to theory, if low CID increases WUE, and higher WUE implies higher seed yield, then CID should be negatively correlated with seed yield. However, CIDLF was not correlated with seed yield in this study on lentil.

SUMMARY

1) Carbon isotope discrimination variability was due to differences in flowering time.
2) The ranking of lentil cultivars for carbon isotope discrimination and seed yield remained constant across locations and years.
3) Carbon isotope discrimination of leaves at flowering was not correlated with seed yield.

CONCLUSION

Carbon isotope discrimination cannot be used to indirectly select for improved seed yield in lentil.

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