ELSEVIER

Thermochimica Acta 349 (2000) 131–134

thermochimica acta

www.elsevier.com/locate/tca

Respiration as measured by scanning calorimetry reflects the temperature dependence of different soybean cultivars

Daniel J.B. Hemming[a,b], Thomas A. Monaco[a], Lee D. Hansen[c], Bruce N. Smith[a,*]

[a]*Department of Botany and Range Science, Brigham Young University, Provo, UT 84602, USA*
[b]*Basic Vegetable Products, 700 Airport Drive, King City, CA 93930, USA*
[c]*Department of Chemistry and Biochemistry, Brigham Young University, Provo, UT 84602, USA*

Received 19 July 1999; received in revised form 12 August 1999; accepted 19 August 1999

Abstract

Soybean [*Glycine max* (L.) Merr.] is grown in many countries and climates. Twenty-two North American soybean cultivars from six different maturity groups were grown from seed under the same conditions. Measurement of metabolic heat rate of leaf tissue with a scanning calorimeter revealed that the slope of heat rate versus temperature when plotted on Arrhenius axes showed abrupt changes reflecting changes in metabolism. The chilling response temperature for all cultivars was near 17.5°C. The maximum tolerable temperature for all cultivars was near 43.5°C. Differences in response to temperatures between the extremes relate to maturity group, follow latitudinal trends, and represent adaptation to different climates. Smaller differences were also observed between cultivars in the same maturity group. Selection of cultivars of soybean for best growth in different climates has resulted in relatively rapid adaptation to local temperatures.

Keywords: *Glycine max*; Cultivars; Respiration; Soybean; Temperature

1. Introduction

Soybean [*Glycine max* (L.) Merr.] cultivars are placed in maturity groups that identify zones of adaptation based on rate of maturation and development. Metabolism influences and is an indicator of plant growth rate [1–3]. Substrates required for tissue construction and growth are closely related to metabolic processes [4–6]. Metabolic comparisons of cultivars from different maturity classes at different temperatures may help guide future selections of new soybean genotypes for growth in a given climate. The purpose of this study is to determine metabolic heat rates for several cultivars from different maturity groups over a wide range of temperatures, and seek correlations with climates of origin.

2. Materials and methods

Soybean [*Glycine max* (L.) Merr.] seed was obtained from Canada, Iowa, and Mississippi in 1994 and kept refrigerated until germinated. Cultivars from Canada were OT 92-12, Maple Presto, and Maple Ridge from maturity Group 000; AC Harmony, Maple Glen, and Maple Isle from Group 00; and AC 9063, Maple Arrow, and Maple Donovan from Group 0. Cultivars from Iowa were in maturity Group II:

* Corresponding author. Tel.: +1-801-378-4885; fax: +1-801-378-7499.
E-mail address: bruce_smith@byu.edu (B.N. Smith)

0040-6031/00/$ – see front matter
PII: S0040-6031(99)00505-5

Lindarin 63, BSR 201, Pride, B216, 92.592, and Hawkeye 63. From Mississippi the cultivars in maturity Group IV were DP 3478, Pioneer 9501, HBK 49 and RA 452. Other southern cultivars from Group V were Asgrow 5979, Hutcheson, DP 3589, and Pioneer 9592.

Plants were grown from seed in an organic potting mix in 1 l pots with a 16 h photoperiod maintained at 20–23°C. Plants were watered daily with 100 ml of Hoagland nutrient solution. Measurements were made at approximately the 10 day/six leaf stage. Stages of plant development are according to Fehr et al. [7]. Calorimetric data were obtained for 22 cultivars (Table 1).

Recently unrolled trifoliates at the V3 developmental stage [7] were removed from plants and metabolic heat rates measured by continuous temperature scanning calorimetry (Hart Scientific model 7707, Pleasant Grove, UT) according to previously published procedures [8]. Temperature was scanned at 10°C h^{-1} from 10 to 55°C with data collected every minute. Leaflets were then oven dried at 70°C and metabolic heat rate calculated on a dry weight basis (μW mg/DW). Calorimetric scans were made for three different plants from each cultivar. Data presented is the mean of the three scans with standard error indicated. Metabolic heat rates for each cultivar were plotted on Arrhenius axes, i.e. ln(heat rate) versus T^{-1}

Table 1
Temperatures (°C) of abrupt slope changes in Arrhenius temperature scans between 10 and 55°C. Each value is average±calorimeter drift of at least two continuous scans. Maturity groups range from Ontario, Canada (Group 000) to Mississippi, USA (Group V)

Cultivar	Observed slope changes (°C)			T_{max}
Maturity Group 000				
Maple Presto	17.7±0.5	25.8±2.1		44.0±1.0
Maple Ridge	16.3±0.5	26.5±0.5		44.0±1.0
OT 92-12	15.0±0.4	25.4±1.9		44.5±0.5
Maturity Group 00				
AC Harmony	16.6±0.4	24.0±1.0		43.0±1.3
Maple Glen	15.7±0.4	25.0±1.0		42.3±0.2
Maple Isle	17.7±0.5	25.7±0.9		42.2±0.9
Maturity Group 0				
AC 9063	16.5±1.2	24.8±1.0		42.2±0.9
Maple Arrow	17.0±0.0	23.7±0.5		42.7±0.5
Maple Donovan	16.7±0.4	23.7±0.9		43.7±0.9
Maturity Group II				
Lindarin 63	17.5±0.0	26.0±0.0		43.0±0.0
BSR 201	17.5±0.0	26.0±0.0		45.0±0.0
Pride B216	17.5±0.0	27.0±0.0		43.0±0.0
92.592	17.5±0.0	26.0±0.0		43.0±0.0
Hawkeye 63	17.5±0.0	26.0±0.0	33.0±0.0	43.0±0.0
Maturity Group IV				
RA 452	16.5±0.5	29.0±1.0	36.0±0.0	44.5±2.5
HBK 49	17.8±1.8	27.0±1.0	36.7±0.5	44.7±1.3
DP 3478	18.3±0.8	27.8±0.3	37.5±0.0	43.3±0.8
Pioneer 9501	17.7±0.5	28.7±0.5	37.2±0.2	42.5±0.0
Maturity Group V				
Asgrow 5979	18.0±0.0	23.7±0.5	36.0±0.04	44.3±0.9
Hutcheson	17.8±1.0	28.2±0.6	37.7±0.2	44.0±1.0
DP 3589	16.2±1.0	24.3±0.9	36.8±0.8	44.7±1.3
Pioneer 9592	16.2±0.6	29.7±0.5	35.7±0.5	44.3±0.9

(K^{-1}) and the plots examined for abrupt changes in slope. Each plot contains about 150 data points; lines shown are linear connections between points. Temperatures at which the slope changed, indicating a change in the metabolic reactions, are reported for each cultivar, as well as the temperatures where the maximum metabolic heat rate was observed.

3. Results and discussion

Fig. 1 illustrates the data obtained with the microcalorimeter. Maple Glen is from maturity Group 00, Pioneer 9592 is from maturity Group V, while Hawkeye is an older cultivar from maturity Group II. The vertical arrow points associated with each curve identify temperatures of slope-change indicating thermally-triggered metabolic changes. Similar curves have been obtained in triplicate for all 22 cultivars. Temperatures of abrupt slope changes in Arrhenius curves for all cultivars and maturity groups are given in Table 1. A chill response occurred below 17.5°C (range 15.0–18.3°C) [2,9]. A second slope change was evident around 27°C (range 24.0–29.7°C) for all 22 cultivars. A third slope change occurred around 35°C (range 33.0–37.7°C), but only in the southern maturity Groups IV and V, and Hawkeye in Group II. The slope change occurring at the highest temperature in all maturity classes and cultivars was at 43.5°C (range 42–45°C) and represents response to high temperature stress.

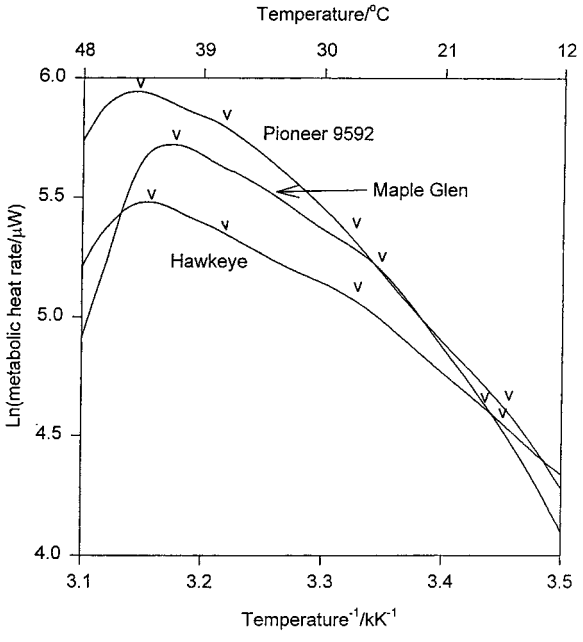

Fig. 1. Sample curves from temperature scanning experiments for one cultivar from each of three maturity groups. Maple Glen is from maturity Group 00; Hawkeye from maturity Group II; and Pioneer 9582 from maturity Group V. The raw data were blank and heat capacity corrected, then plotted on Arrhenius axes. Arrows (v) indicate temperatures of abrupt deviations from linear Arrhenius behavior which signify changes in metabolic reactions in the tissues. Each plot contains about 150 data points; lines shown are linear connections between points.

Soybean respiration rates were greatest in leaflets recently unrolled (V3), where a greater portion of the leaf is involved in cell division and expansion than is the case for older leaves. Similarly, Sesay et al. [10] found that respiration rate declined consistently with leaf age, and others have suggested this is due to maintenance respiration dominating in older leaves [11,12]. Kishitani and Shibles [13] reported that mature leaves from a high yielding soybean cultivar respired less than a low yielding cultivar. Our gas exchange results (data not included) did not show a clear relationship between respiration rates and maturity classes. Interpretation of the relationship between temperature, respiration, and yield is difficult [14]. A technique has been developed [2] that allows a determination of both respiration rate and heat rate for the same tissue at different temperatures. The ratio of the two is a measure of metabolic efficiency. Efficiency as well as respiration can affect crop yield. Our attempts to measure efficiency failed however, apparently because of sensitivity of the soybean leaves to handling and/or changes in CO_2 concentrations [12,15,16].

Scanning experiments provide useful insights into the temperature-growth relation by revealing temperatures where metabolism changes. Low and high stress temperatures are similar for all cultivars and maturity groups, thus it would seem that all soybeans have a relatively recent common origin. But, as seen in Table 1, differences were found between maturity groups at intermediate temperatures. Knowing the temperatures where changes in metabolism occur may assist in selection of appropriate soybean cultivars for specific climatic conditions.

4. Conclusions

1. The chilling response temperature for all 22 cultivars was near 17.5°C and the maximum tolerable temperature for all cultivars was near 43.4°C, indicating that all cultivars have a recent common origin.
2. Between the extreme temperatures, differences in metabolic response to temperature were related to maturity groups, follow latitudinal trends and represent adaptation to different climates.

Acknowledgements

We thank Dr. Richard Shibles (Iowa State University), Dr. Hugh Pope (Plant Research Centre, Ottawa, Canada), and Dr. Larry Heatherly (USDA Soybean Production Research Center, Stoneville, Mississippi) for providing soybean seed used in these experiments. For technical help and laboratory assistance, we thank Angela Jones, Jennifer McGee, and David Moulton. Financial assistance was provided by the Departments of Botany and Range Science and Chemistry and Biochemistry at Brigham Young University, and the Dow Chemical Company.

References

[1] R.S. Criddle, M.S. Hopkin, E.D. McArthur, L.D. Hansen, Plant Cell and Environment 17 (1994) 233.
[2] L.D. Hansen, M.S. Hopkin, D.R. Rank, T.S. Anekonda, R.W. Breidenbach, R.S. Criddle, Planta 194 (1994) 77.
[3] J.A. Mullen, H.R. Koller, Plant Physiology 86 (1988) 517.
[4] B.M. Coggesshall, H.F. Hodges, Crop Science 20 (1980) 86.
[5] T.C. Hrubec, J.M. Robinson, R.P. Donaldson, Plant Physiology 79 (1985) 684.
[6] W.O. James, An Introduction to Plant Physiology, 4th Edition, Oxford University Press, London, 1946, p. 102.
[7] W.R. Fehr, C.E. Caviness, D.T. Burmood, J.S. Pennington, Crop Science 11 (1971) 929.
[8] R.S. Criddle, R.W. Breidenbach, L.D. Hansen, Thermochimica Acta 193 (1991) 67.
[9] D.R. Rank, R.W. Breidenbach, A.J. Fontana, L.D. Hansen, R.S. Criddle, Planta 185 (1991) 576.
[10] A. Sesay, C.R. Stewart, R.M. Shibles, Plant Physiology 82 (1986) 443.
[11] J.S. Amthor, Respiration and Crop Productivity, Springer, Berlin, 1989, p. 125.
[12] J.A. Bunce, L.H. Ziska, Annals of Botany 77 (1996) 507.
[13] S. Kishitani, R. Shibles, Crop Science 26 (1986) 580.
[14] I.R. Johnson, J.H.M. Thornley, Annals of Botany 55 (1985) 1.
[15] D.J.B. Hemming, M.S. Thesis, Brigham Young University, Provo, Utah, USA, 1995, p. 56.
[16] R.B. Thomas, K.L. Griffen, Plant Physiology 104 (1994) 355.