PROPERTIES OF RAPESEED 1. THERMAL CONDUCTIVITY AND SPECIFIC HEAT

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INTRODUCTION

Rapeseed has become an important Canadian crop. While the greatest interest is in the oil produced, the use of the high protein meal in animal feeding is increasing in importance. High prices and heavy demand for soybean meal on the international market have increased the emphasis on rapeseed meal as an alternative feed.

As one step in the processing of rapeseed, the temperature of the seed is raised rapidly to about 100°C for the destruction of myrosinase. This step is necessary both for the production of high quality meal and for the production of oil which is low in thiocyanate compounds. The effectiveness of the heat treatment is dependent on the moisture content of the seed as well as the heat penetration.

To effectively design new thermal processing methods or revise existing procedures it is essential to know the heat transfer and heat capacity characteristics of the rapeseed.

This report deals with the thermal conductivity, thermal diffusivity and specific heat of bulk rapeseed in both the whole and ground state. The influence of moisture content on these parameters is examined.

REVIEW OF LITERATURE

Several workers have studied the thermal properties of various grains and oilseed crops. Grains of various types were considered by Kazarian and Hall (4) and more recently the properties of grain sorghum were studied by Sharma (7), those of spring wheat by Chandra (1), and the specific heat of wheat by Muir (5) and Pfalzner (6). Jasansky (3) examined the thermal conductivity of whole and ground soybeans. These authors considered the effects of moisture content and temperature on the measured parameters. Both transient and steady state methods have been used to measure conductivity. For the present study the pseudo steady state method of Dickerson (2) was used.

Contribution No. 506 from Engineering Research Service, Ottawa, Ontario

RECEIVED FOR PUBLICATION FEBRUARY 24, 1975.

MATERIALS AND METHODS

The rapeseed used for the trials was obtained from Western Canadian Seed Processors Ltd., Lethbridge, Alberta. The seed was identified as cleaned Canada No. 1 Grade seed of the Echo (Polish) variety. Comparative tests were run using the cultivars Oro, Target, Arlo and Bronowski.

Specific Heat

A small calorimeter (8) was used to determine specific heat. The calorimeter consisted of a well insulated 500-ml dewar flask equippped with a small electric motor and stirring rod for agitation and an upper chamber to facilitate sample loading. Test samples were held in a small container (about 40 cm^3) formed from 0.127-mm thick brass. A thermocouple was mounted with its measuring junction at the geometric center of the sample container. A second matched thermocouple in the calorimeter water was wired differentially to the sample thermocouple to sense the temperature difference between the sample and the calorimeter water. A third thermocouple was used to record the calorimeter water temperature.

Two stable d-c amplifiers were used to amplify the thermocouple signals which were then recorded on a two-pen millivolt recorder. The thermocouple circuits were calibrated for each run against calorimetry thermometers accurate to ±0.01°C (traceable to National Bureau of Standards). Calibration runs were conducted on the calorimeter to determine the thermal constants of the sample holder, stirring rod and thermocouples under operating conditions. Water was used as a sample during calibration.

For each test the sample container was filled, weighed and then equilibrated to temperature in a well stirred ice bath. The calorimeter dewar flask was filled with a measured amount of water and allowed to equilibrate to temperature. The sample container was then immersed in the calorimeter water and specific heat calculated from the temperature values obtained.

Thermal Diffusivity

Thermal diffusivity tests were conducted using apparatus and techniques similar to those of Dickerson (2). Samples were enclosed in a 5-cm diam brass cylinder, 23 cm long and fitted with surface and geometric center temperature thermocouples. The sample cylinders were immersed in a well stirred water bath and the temperature increased linearly from 25 to 90°C using a programmed power supply. Temperatures were recorded with a multipoint recorder. The thermal diffusivity was calculated from the lag of the center temperature as:

$$\propto = \frac{Ar^2}{4\,(\Delta T)}$$

where

$\propto$	=	thermal diffusivity
A	=	heating rate (°C/min)
r	=	radius of cylinder (cm)
ΔT	=	temperature difference between center and surface (°C)

Thermal conductivity was determined from the relationship

$$k = \propto C_p \rho$$

where

k = thermal conductivity
α = thermal diffusivity
C_p = specific heat
ρ = density

Density was carefully measured for each sample and specific heat was determined as previously outlined.

Sample and Sample Preparation

The moisture content of the rapeseed was adjusted by equilibrating the seed to constant weight over various saturated salt solutions at 24°C. The salts and their respective humidities used for equilibration were: lithium chloride, 11%; potassium acetate, 23%; magnesium chloride, 33%; potassium carbonate, 43%; magnesium nitrate, 52%; cupric chloride, 67% and sodium chloride, 75%. Two high humidities were attempted but these were discontinued when the seed was found to rapidly develop a mold growth.

Density

Densities of the rapeseed at four test relative humidities (33, 43, 67, 75%) were measured using a small weight per bushel tester. The density was also measured during each of the thermal diffusivity tests from the sample holder volume and sample weight.

Specific heats and thermal diffusivities of rapeseed were determined on seed equilibrated over various salt solutions as summarized in Table I.

RESULTS AND DISCUSSION

Tables II through V summarize the results of thermal conductivity, thermal diffusivity and specific heat for the whole and ground Echo seed at seven moisture contents and for the four cultivars, Arlo, Oro, Target and Bronowski each at two moisture contents.

Specific Heat

The specific heat of rapeseed varied with the moisture content of the samples. Specific heat increased from a low of 0.33 cal/g°C at 3.8% moisture to a high of 0.46 at a moisture content of 9.7% (Figure 1). There were no marked differences between the five varieties. Table V shows the values for the four varieties checked after equilibration at two relative humidities in comparison with the values for Echo.

The values found for specific heat of rapeseed were similar to values for a

TABLE I SUMMARY OF TESTS USED FOR THE DETERMINATION OF SPECIFIC HEAT AND THERMAL DIFFUSIVITY

Cultivar	Sample form	Relative humidity† (%)	Replications
Echo	Whole seed	11, 23, 33, 43, 52, 67, 75	2 at each humidity
Echo	Ground seed	11, 23, 33, 43, 52, 67, 75	2 at each humidity
Echo	Whole seed	75	9
Echo	Whole seed	11, 67	2
Target	Whole seed	11, 67	2
Bronowski	Whole seed	11, 67	2
Arlo	Whole seed	11, 67	2
Oro	Whole seed	11, 67	2

† Seed samples were equilibrated over salt solutions at the various relative humidities before testing.

TABLE II SPECIFIC HEAT, THERMAL DIFFUSIVITY AND THERMAL CONDUCTIVITY IN WHOLE ECHO RAPESEED

Sample equilibration (% RH)	Moisture content (%)	Specific heat (cal/g°C)	Thermal diffusivity (cm^2/min)	Thermal conductivity (cal/cm^2 min °C/cm)
11	3.83	.368	.058	.015
23	4.37	.369	.057	.015
33	5.02	.390	.058	.016
43	5.70	.414	.060	.017
52	6.60	.415	.061	.018
67	8.07	.437	.063	.020
75	9.70	.461	.065	.021

Conversion Factors
1 Btu/hr ft^2 °F/ft = 0.247 cal/cm^2 min °C/cm = 1.724 W/m °K
1 Btu/lb °F = 1 cal/g °C = 239 J/kg °K
1 ft^2/hr = 15.48 cm^2/min.

TABLE III SPECIFIC HEAT, THERMAL DIFFUSIVITY AND THERMAL CONDUCTIVITY ON WHOLE ECHO SEED AT CONSTANT MOISTURE ACHIEVED BY SAMPLE EQUILIBRATION AT 75% RH

Moisture content (%)	Specific heat (cal/g °C)	Thermal diffusivity (cm^2/min)	Thermal conductivity (cal/cm^2 min °C/cm)
9.25	0.433	.063	.019
9.25	0.431	.065	.019
9.35	0.420	.063	.018
9.47	0.435	.064	.020
9.32	0.431	.065	.020
9.05	0.409	.065	.019
9.07	0.401	.066	.019
9.30	0.419	.066	.018
9.20	0.438	.065	.020
9.15	0.457	.065	.021

TABLE IV SPECIFIC HEAT, THERMAL DIFFUSIVITY AND THERMAL CONDUCTIVITY IN GROUND ECHO RAPESEED

Sample equilibration (% RH)	Moisture content (%)	Specific heat (cal/g °C)	Thermal diffusivity (cm^2/min)	Thermal conductivity (cal/cm^2 min °C/cm)
11	3.97	.367	.062	.011
23	4.43	.352	.061	.010
33	5.10	.364	.063	.011
43	5.80	.372	.063	.011
52	6.37	.425	.064	.012
67	8.1	.440	.069	.013
75	9.8	.406	.074	.014

variety of other grains. For example, Pfalzner (6) gives values for wheat as 0.32 cal/g°C at 4% moisture and 0.35 – 0.37 at 10%. Kazarian (4) gives specific heats of 0.404 at 5.08% moisture and 0.438 at 9.81% for yellow dent corn and 0.375 at 5.45% moisture and 0.428 at 10.3% for soft wheat. Sharma (7) found the specific heat of grain sorghum to be about 0.37 and 0.42 at 5 and 10% moisture, respectively.

Density

The density of whole rapeseed as measured using a weight per bushel tester ranged from 0.65 g/cm^3 to 0.69 g/cm^3. During testing for thermal diffusivity, densities were also determined from the volume of the cell and the weight of seed. In the latter case the cells were not filled from a dropping funnel at a specific height as in the former. Slightly higher densities were recorded from this test ranging from 0.68 to 0.72 g/cm^3. This was attributed to settling and packing during hand filling by the operator. Changes in density with moisture content were inconsistent and a general trend was not indicated. Individual samples of the five varieties all fell into the same range although one sample of Oro at 9% moisture had a density of 0.625 g/cm^3. The density of the ground Echo seed dropped as the moisture content increased from 4 to 10%. This decrease was from 0.49 g/cm^3 to 0.42 g/cm^3. Densities of the ground seed are considerably lower than for the whole seed, as would be expected.

Thermal Diffusivity and Thermal Conductivity

The thermal diffusivity of whole rapeseed was found to range from 0.055 to 0.066 cm^2/min for the five varieties tested over the range of moisture content from 3.8 to 9.7%. Of greater interest for processing is the thermal diffusivity above a moisture content of 6%. Figure 2 shows the influence of moisture content on the thermal diffusivity of the whole rapeseed. The thermal diffusivity increased with moisture content over the range of moistures studied, increasing by about 13% for the increase in moisture from 3.5 to 9.7% (Figure 2.)

Thermal diffusivity of the crushed seed showed a trend similar to that of the whole seed by increasing with moisture content. Thermal diffusivity in the ground seed was somewhat higher than for the whole seed. For the coarsely ground seed, thermal diffusivity increased from 0.061 to 0.074 cm^2/min as the moisture content was increased from 3.97 to 9.8%.

TABLE V SPECIFIC HEAT, THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY OF DIFFERENT VARIETIES OF RAPESEED

Cultivar	Sample equilibration (% RH)	Moisture content (%)	Specific heat (cal/g °C)	Thermal diffusivity (cm^2/min)	Thermal conductivity (cal/cm^2 min °C/cm)
Target	11	3.30	.365	.057	.015
Target	67	7.87	.439	.061	.019
Echo	11	3.83	.368	.058	.015
Echo	67	8.07	.437	.062	.020
Bronowski	11	4.12	.342	.058	.013
Bronowski	67	8.70	.405	.065	.018
Arlo	11	3.95	.359	.058	.015
Arlo	67	8.45	.412	.062	.018
Oro	11	3.62	.367	.058	.014
Oro	67	8.40	.428	.066	.018

TABLE VI RANGES OF THERMAL CONDUCTIVITY FOR VARIOUS GRAINS

	Btu/hr ft^2 °F/ft	cal/cm^2 min °C/cm
Whole rape	0.061 – 0.081	0.015 – 0.021
Ground rape	.045 – .057	.011 – .014
Whole soybean	0.055 – .078	.014 – .019
Ground soy	.050 – .070	.012 – .017
Wheat	0.075 – .087	.019 – .021
Corn	0.102	.025
Oats	0.037 – 0.075	.009 – .019

As noted earlier, thermal conductivity and thermal diffusivity are related as:

$$\alpha = \frac{k}{\rho C_p}$$

Many values have been given in the literature for conductivity of various grains and a comparison of rapeseed with these values appears useful. (Table VI). The values for rape are very similar to those for soy, particularly in the whole seed. For crushed rape the values are in the lower range for the crushed soy. The values for the crushed seed would be expected to vary with particle size as Jasansky (3) found with soybeans; however, this aspect was not studied.

CONCLUSIONS

The specific heat of rapeseed was in the same range as the reported values for several other grains. Specific heat ranged from 0.33 to 0.46 cal/g°C. Similarly, the thermal conductivity for rapeseed was in the same range as other grains and oilseeds, particularly soy. Moisture content influenced the parameters studied. Specific heat and thermal conductivity increased with the increasing moisture in the range studied. No appreciable differences in specific heat or conductivity were found between the five varieties of seed examined.

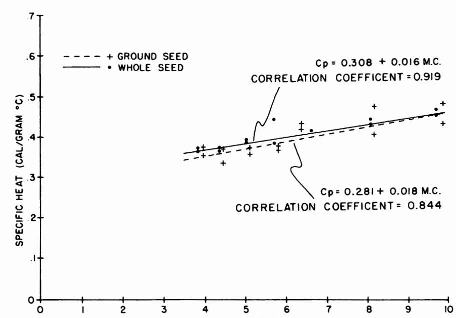

Figure 1. Influence of moisture content on specific heat of rapeseed.

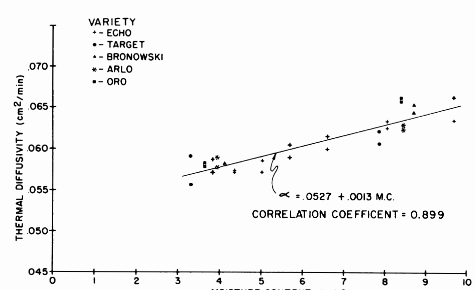

Figure 2. Influence of moisture content on thermal diffusivity of rapeseed.

SUMMARY

The thermal properties of rapeseed are important in relation to the processing of the seed to destroy myrosinase prior to

oil extraction. This study gives the results of tests determining the specific heat and thermal diffusivity of rapeseed. Moisture content influenced the parameters measured. The thermal conductivity for rape was in the same range as values reported elsewhere for soybeans and meal. No great differences were found between the five varieties tested.

ACKNOWLEDGMENTS

The author would like to acknowledge the technical assistance of G.D. Robertson, and thank Dr. J. Jones of the Food Research Institute who supplied the rapeseed samples. Financial assistance of the Rapeseed Association is also acknowledged.

REFERENCES

1. Chandra, S. and W.E. Muir. 1971. Thermal conductivity of wheat at low temperatures. Trans. Amer. Soc. Agric. Eng. 14: 644-646.
2. Dickerson, R.W. 1965. An apparatus for the measurement of the thermal diffusivity of foods. Food Technol. 19: 880-886.
3. Jasansky, A. and W.K. Bilanski. 1973. Thermal conductivity of whole and ground soybeans. Trans. Amer. Soc. Agric. Eng. 16: 100-103.
4. Kazarian, E.A. and C.W. Hall. 1965. Thermal properties of grain. Trans. Amer. Soc. Agric. Eng. 8: 33-48.
5. Muir, W.E. and S. Viravanichai. 1972. Specific heat of wheat. J. Agric. Eng. Res. 17: 338-342.
6. Pfalzner, P.M. 1951. The specific heat of wheat. Can. J. Technol. 29: 261-268.
7. Sharma, D.K. and T.L. Thompson. 1973. The specific heat and thermal conductivity of grain sorghum. Trans. Amer. Soc. Agric. Eng. 16: 114-117.
8. Timbers, G.E. 1973. Thermal diffusivity and specific heat of rapeseed. Report 7142-1. Engineering Research Service, Research Branch, Agriculture Canada, Ottawa, Ont.