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Vapour Pressure and Moisture Equilibria in Rapeseed

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1.0 Introduction

Rapeseed processing in Canada has grown to be a relatively large industry. Acreage planted is in the 3 million range and crushing plants are now being established in the east as well as the prairies. Very little data has been published to date on the equilibrium moisture content of rapeseed.

The equilibrium moisture content of rapeseed is of particular importance in reference to the moisture levels required for processing of the seed. The necessity of having the moisture content above 6% for the inactivation of myrosinase during processing will govern the storage relative humidities which can be used.

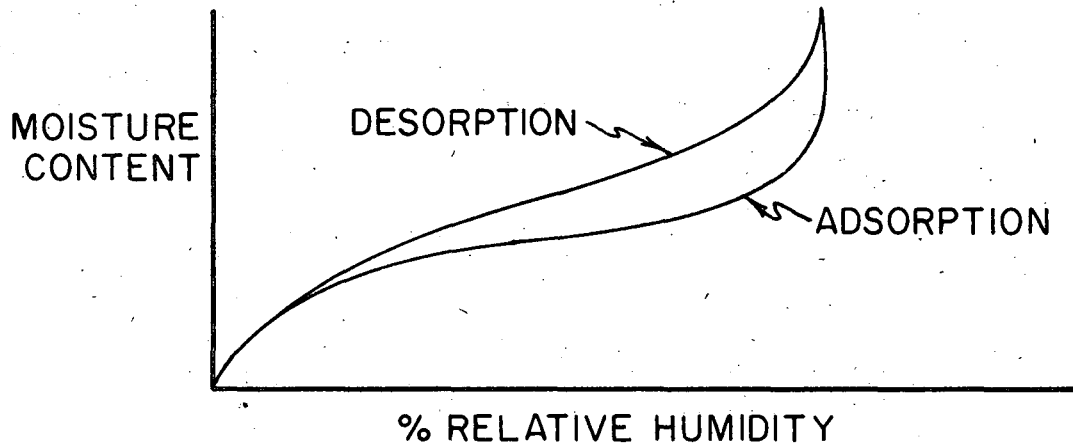
This report gives data on the sorption isotherms for rapeseed and the vapour pressure generated by the moisture in the seed over a temperature range of 15° to 60°C, while the majority of testing was done with the Echo variety. Bronowski, Arlo, Oro and Target were also checked.

2.0 Review of Literature

2.1 Equilibrium moisture content - Theory

Several authors have discussed equations to fit moisture equilibria data. Labuza (1968) discusses several approaches to the subject, and reviews various aspects of sorption and water activity. He discusses the three approaches of (1) kinetic (Langmuir isotherm); (2) potential (including Harkins - Jura isotherm) and (3) capillary condensation. Henderson (1952) developed an empirical equation to cover the complete sorption isotherm. Strohman (1967) developed an equation for equilibrium moisture starting from the Othmer plots of the data. Details regarding the use of the Othmer plots for latent heat and vapour pressure are given by Othmer (1940). Brunauer (1938) extended the Langmuir isotherm approach with the BET theory. This approach has been used by quite a few workers, and was considered by Labuza (1968) to be most useful in predicting monolayer values and heat of adsorption. The BET approach seems to hold up to an activity of about 0.5.

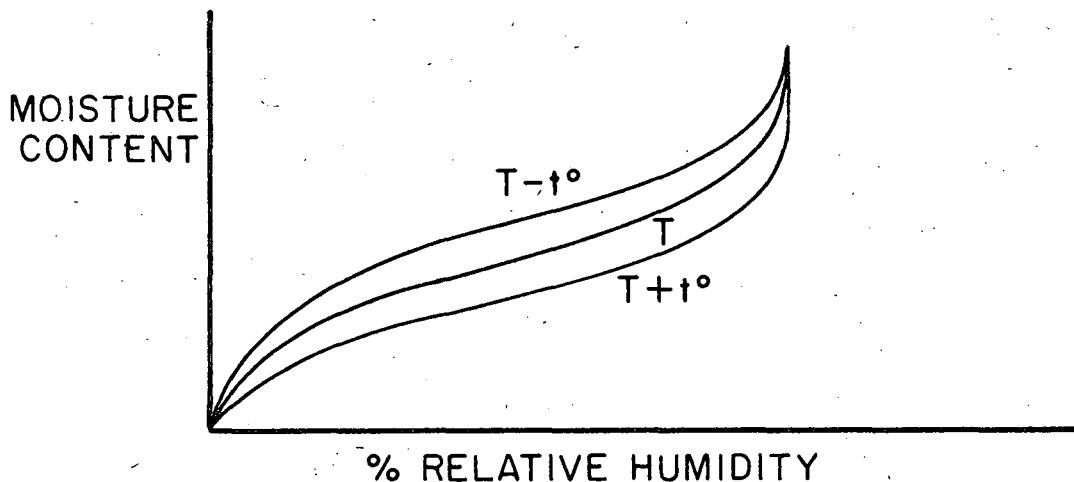
The general forms of the sorption isotherms are outlined in the following:



General form of the sorption isotherm

This general sigmoid shaped isotherm is characteristic for most food and agricultural products. Labuza (1968) points out that over most of the upper range the water activity is near one, the value for pure water, but at lower moistures (the last 10 - 20% of the water in the material) the water activity decreases. This latter area is that of interest for dehydration and storage of food products.

Temperature plays a role in the sorption isotherm form, with increased temperature decreasing the moisture content at any given relative humidity.



Influence of temperature on sorption isotherms shown diagrammatically.

The BET isotherm has been used quite widely for describing water sorption in food products. This form of the sorption isotherm is often given as:

$$\frac{a}{(1-a)v} = \frac{1}{v_m C} + \frac{a(C-1)}{v_m C}$$

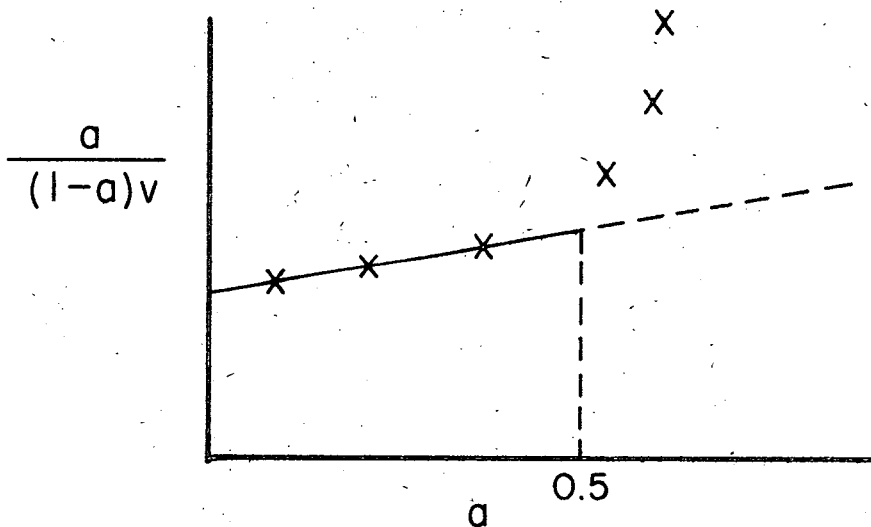
where $C = k \exp(Q_s/RT)$

$k = \frac{\text{accommodation coefficient}}{\text{frequency factor}} = 1$

$v =$ volume adsorbed in g/g or cc/g

$v_m =$ monolayer value

Plotting the BET isotherm as $a/(1-a)v$ vs a should yield a straight line. The slope $(\frac{C-1}{Cv_m})$ and intercept coefficient $(\frac{1}{Cv_m})$ can be used to calculate the monolayer coverage value. Labuza (1968) points out that the BET isotherm usually holds only between activities of 0.1 to 0.5. The heat of adsorption can also be calculated from this plot.

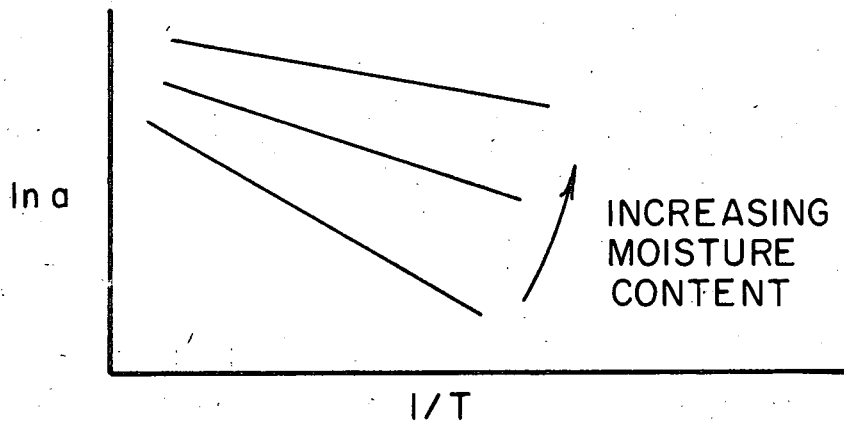


General form of the BET isotherm

Most sorption phenomena obey the Clausius - Clapeyron relationship:

$$\frac{d (\ln a)}{d (1/T)} = - \frac{Q_s}{R}$$

Plotting $\ln a$ vs the reciprocal of the absolute temperature should give a straight line and provide a means for calculating the heat of adsorption, Q_s (Labuza 1968, Berry 1973).



Clausius - Clapeyron plot of sorption isostere

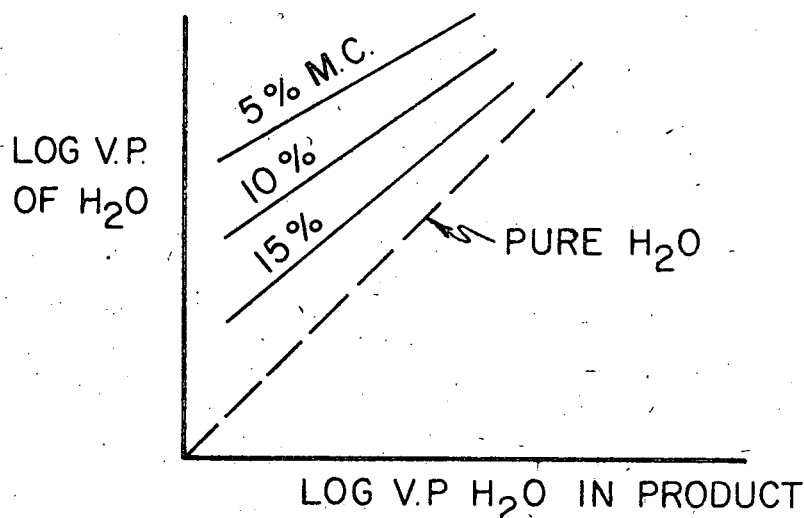
Henderson (1952) developed an empirical relationship in an effort to cover the complete sorption isotherm. Two constants or factors characteristic of the material are required in the equation.

$$1 - rh = e^{-k' M^n}$$

Values for the two constants for various materials are given in several sources (Henderson, 1952). Pichler (1957) found quite good agreement for wheat with Henderson's equation but not for rape. Calculation of k' and n for rape from two pairs of relative humidities at 20°C did not give agreement, let alone agreement with values calculated at different temperatures.

The plotting technique devised by Othmer (1940) has been applied to agricultural products (Haynes 1961, Strohman 1967). The Othmer plot relates the vapour pressure exerted by the moisture in the product with the vapour

pressure of water at the same temperature. In his derivation Othmer assumes (1) ideal gas law holds; (2) vol. of condensed phase is insignificant compared with vapour phase and (3) ratio of the latent heats remains nearly constant. With these assumptions the data should give linear plots of the form shown below.



General form of the Othmer plot

The slopes of the lines in the Othmer plot can be used in the determination of the latent heat of water in the product.

2.2 Equilibrium moisture in various products

Many papers have been written on equilibrium moisture content, on a wide range of products. Henderson (1952) fitted his equation with such products as corn, wheat, sorghum, soybeans, flax, raisins, dried peaches and prunes, cotton, leather, wood, dried eggs and clays. Wheat has received considerable attention (Day 1965, Pichler 1957, Gay 1946, Young 1967, Haynes 1961). Among the other products that have been studied are rice (Agrawal 1971, Karon 1949, Hogan 1955), dry beans (Weston 1954), soybeans (Saravacos 1969), sunflower (Kilara 1972) and flaxseed (Larmour 1944).

2.3 Methods of measurement of moisture sorption

Several methods have been used to determine moisture equilibria in food and agricultural products. The methods have been reviewed by Smith (1971).

Sorption isotherms may be determined by equilibrating the material over saturated salt solutions and measuring the moisture content. This is perhaps the simplest method but it is time consuming, because static equilibration is slow. Air circulation above the salt solutions increases the rate of equilibration. Magnetically coupled fans provide a simple solution (Wink 1946, Bosin 1970).

Selection of salt solutions to provide any given relative humidities is facilitated by several references to humidities above saturated salt solutions (Rockland 1960, Wink 1950, Richardson 1955, Hygrodynamics). A typical set of values for salt solutions to cover a wide range of relative humidities is reproduced in Table 1.

Table 1. EQUILIBRIUM RELATIVE HUMIDITIES FOR SATURATED SALT SOLUTIONS

Saturated Salt Solution	Formula	Percent Relative Humidity at State Temperatures		
		68°F(20°C)	77°F(25°C)	86°F(30°C)
Lithium Chloride	LiCl · H ₂ O	12.4	12.0	11.8
Potassium Acetate	KC ₂ H ₃ O ₂	23.3	22.7	22.0
Magnesium Chloride	MgCl ₂ · 6H ₂ O	33.6	33.2	32.8
Potassium Carbonate	K ₂ CO ₃ · 2H ₂ O	44.0	43.8	43.5
Potassium Nitrite	KNO ₂	49.0	48.1	47.2
Magnesium Nitrate	Mg (NO ₃) ₂ · 6H ₂ O	54.9	53.4	52.0
Sodium Nitrite	NaNO ₂	65.3	64.3	63.3
Sodium Chloride	NaCl	75.5	75.8	75.6
Ammonium Sulfate	(NH ₄) ₂ SO ₄	80.6	80.3	80.0
Potassium Nitrate	KNO ₃	93.2	92.0	90.7
Potassium Sulfate	K ₂ SO ₄	97.2	96.9	96.6

Other methods for determining the sorption characteristics of products are based on the vapour pressure of the water in the product or the relative humidity above the product. Legault (1948) used specially built apparatus which included a Dubrovin manometer to measure the pressure. Haynes (1961) used an isotenoscope to measure seed vapour pressure. Haynes (1961) also used a Dunmore type humidity sensor to study the relative humidity generated by various seeds. Smith (1971) discusses the use of various humidity sensors in reference to the determination of equilibrium relative humidity.

3.0 Material, Equipment and Methods

3.1 Material

All rapeseed samples used in this study were provided by the Food Research Institute, Agriculture Canada. The material was all Canada #1 seed, cleaned and graded. The bulk of the tests were conducted using seed of the Echo variety with comparative tests conducted on Bronowski, Arlo, Oro and Target samples.

3.2 Equipment

3.2.1 Static equilibrium over saturated salt solutions

Equilibration of the seed over salt solutions was performed using three chambers constructed from clear acrylic tube. Each chamber (Fig. 1) was 30 cm diameter by 13 cm high and equipped with a magnetically coupled circulation fan and a screen bottomed holder for the seed. Each chamber could be used to equilibrate 1 kg of seed.

A single chamber similar to that described by Bosin (1970) was used for final equilibration. This chamber was arranged to weigh the sample without removing the sample from the chamber (Fig. 2).

3.22 Vapour pressure measurement

For studying the equilibrium vapour pressure of the rapeseed an isotenoscope assembly similar to that of Haynes (1961) was used (Fig. 3). A stopcock type valve interconnected the two arms of the "U" tube manometer. The isotenoscopes were constructed by an Agriculture Canada glass blower. Flask size used for the isotenoscope was 250 ml. The water bath used for temperature stabilization was controlled by a Haake Model E52 thermoregulator. Vacuum was drawn on the system using a 1/3 hp Fisher Duo Seal pump. Pressure in the system was monitored by a Fisher-Zimmerli mercury manometer. A glass dessicator jar of about 25 cm dia was used as a vacuum reservoir. Any air bled into the system entered through a 20 cm long dessicant column.

3.3 Methods

3.31 Rapeseed pre-equilibration

All seed samples used were pre-equilibrated over saturated salt solutions either at 11% RH or 75% RH. The 1 kg samples were held over the salt solutions for about 2 wks. prior to use in testing. If no weight change was observed between consecutive days weighings, the seed was considered pre-equilibrated.

3.32 Final equilibration

Final equilibration of the seed over the selected saturated salt was performed using 250 g samples in the chamber equipped for in situ weighing. During equilibration the apparatus was located in a controlled temperature room at 23°C. With the continuous air circulation in the chamber constant weight was reached in 4 - 7 days. From this material 75 g was used for the vapour pressure measurement and 30 g for duplicate moisture determinations. The remaining 145 g were stored over saturated salt in still air for duplication runs.

3.33 Moisture Content Determination

After equilibration, seed moisture content was determined using a Brabender Rapid Moisture Tester^a. A 30 g sample was ground and two 10 g samples were used for duplicate moisture determinations. Following vapour pressure determinations using the isotenscope duplicate 10 g samples were again used to determine the final moisture content.

3.34 Vapour Pressure determination

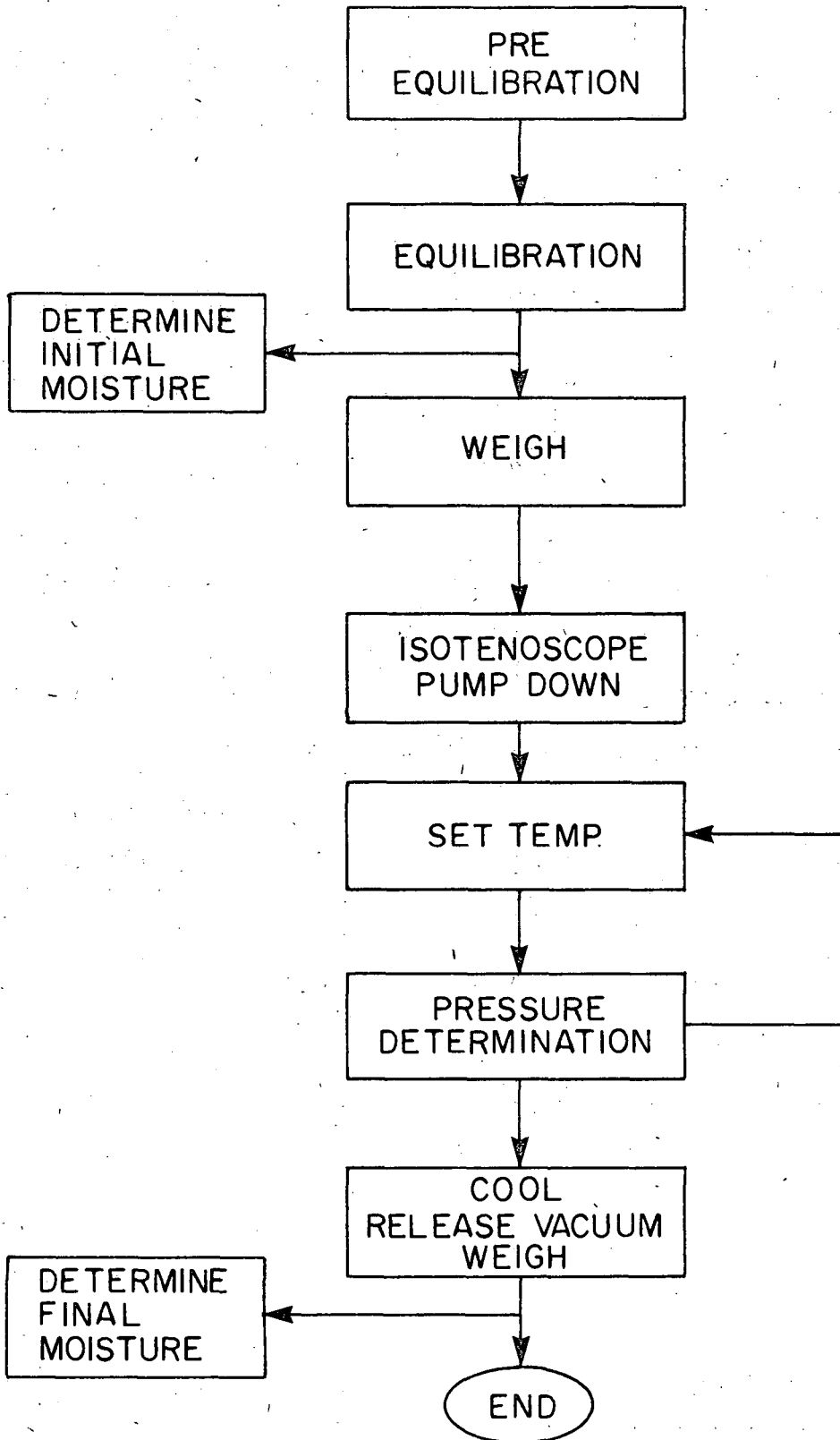
Vapour pressures were measured in the isotenscope system (Fig. 3 & 4). For each test the isotenscope flask was weighed, a 75 g sample of equilibrated seed added and reweighed. With valve A, Fig. 3 and valve A, Fig. 4 open the system was pumped down for 1 hr., allowed to remain under vacuum for 1/2 hr. and then pumped down for a final 1/2 hr. After pump down, both of the above valves were closed and the isotenscope placed in the controlled temp bath. Initial bath temperature was about 15°C. After a 24 hr. period at the controlled temperature a final pressure balancing is done and the vapour pressure read on the manometer. After reading, the temperature was reset and the system rebalanced. Temperatures of 15, 30, 45 and 60°C were used and the seed vapour pressure was allowed 24 hrs. to equilibrate at each temperature. System pressures were balanced either by pumping down with the vacuum pump or allowing atmospheric pressure air into the vacuum reservoir through the dessicator column (Item 6, Fig. 3).

For the later tests using the four additional varieties, temperatures of 25, 45 and 60°C were used.

At the end of each test series, i.e. after a 60°C reading, the isotenscope was removed from the controlled temperature bath, valve "A", fig. 4 opened and the isotenscope allowed to cool. After the sample cooled, vacuum was released by opening valves A and B, Fig. 3, sample weighed and the duplicate moisture samples run.

^aC.W. Brabender Inc., 50 East Wesley St., South Hackensack, New Jersey.

3.35 Flow chart for isotenoscope procedure



A secondary method was used for determining the vapour pressure for the seeds at high moisture content. This was necessary for two reasons. The first that drawing the vacuum on the high moisture seed radically reduces the moisture content and secondly at the higher moisture and higher temperature erroneously high readings are obtained. This appears to be due to mold growth and respiration in the seed. The vapour pressure was determined indirectly by measuring the dew point of the air above the seed using a Cambridge Model 880 dew cell. Air was circulated from the sample container, over the dew cell and returned to the sample container. Sample temperature was regulated by placing the container in a controlled temperature water bath as for the isotenscope. The system was operated in a controlled temperature room at about 5°C higher than the sample temperature. This is necessary to make certain that no condensation could occur in the air lines, circulating pump or flow meter. The dew cell head was also in the controlled temperature room with only the actual meter kept remote.

Seed for the high moisture levels was brought to the desired moisture content by the direct addition of water. Seed with the added water was tumbled in a sealed container for 3 hours.

3.4 Summary of Tests

Whole Seed - Pre-equilibration at 11% RH

<u>Equilibration RH</u>	<u>Temperatures °C</u>			
11%	15	30	45	60
23	15	30	45	60
33	15	30	45	60
43	15	30	45	60
52	15	30	45	60
67	15	30	45	60
75	15	30	45	60

Whole Seed - Pre-equilibration at 75% RH

<u>Equilibration RH</u>	<u>Temperatures °C</u>			
33	17.5	35	45	60
43	21.5	35	45	60
52	28	35	45	60

Crushed Seed - Pre-equilibration at 11% RH

<u>Equilibration RH</u>	<u>Temperatures °C</u>			
11	15	30	45	60
23	15	30	45	60
33	15	30	45	60
43	15	30	45	60
52	15	30	45	60
67	15	30	45	60
75	15	30	45	60

Crushed Seed - Pre-equilibration at 75%

<u>Equilibration RH</u>	<u>Temperatures °C</u>			
11	17.8	31	45	60
33	15	30	45	60
52	15	30	45	60

4.0 Results and Discussion

4.1 Equilibrium Moisture content

Seed samples were equilibrated over the various saturated salt solutions with RH values between 11 and 75% as in section 3.32. Over this range of relative humidities the moisture content increased from about 3.4% (wet basis) up to 9.8% (Fig. 5). Some differences were observed between varieties but from the number of samples it is not possible to tell if the differences are statistically significant. Although very low moisture content values were not obtained, it appears that

the sorption isotherm for rapeseed follows the general sigmoid form found in many agricultural products. Hysteresis is seen between adsorption and desorption (Fig. 6) although the differences between the two curves are not great.

Moisture contents for rapeseed obtained in this study agree with the values obtained by Pichler (1957) over the humidity range considered as is seen below.

	RH%			
	15	25	40	75
Present Study (Fig. 5)	4.3%	4.8	5.8	10.8
Pichler	4.2	5.0	6.0	10.8%

No attempt has been made to fit the data to Henderson's equation, as Pichler (1957) found a poor relationship when using the 25 to 75% rh range. He found reasonable agreement with Henderson's equation using up to 55% rh reference points of 15% and 40% rh. Pichler suggests that the poor agreement at higher moisture is due to water uptake by capillary condensation instead of adsorption.

4.2 Vapour Pressure

The vapour pressure of either crushed or whole rapeseed increases exponentially with temperature and produces a family of roughly parallel lines depending on the sample moisture content (Fig. 7 and 8) when plotted on semi-log paper. All varieties tested had very similar vapour pressures (Fig. 9) over the range of temperatures and moisture contents tested. Vapour pressure at 60°C is near 100 mm Hg for seed with a seed moisture content of about 6% and about 50 mm Hg for seed moisture of about 3.5%.

A more informative means of appraising the vapour pressure, temperature and moisture content relationship is through the use of the Othmer plot (Fig. 10, 11, 12). In this form the vapour pressure of the water in the seed is plotted vs the vapour pressure of pure water using a log-log scale. The solid straight line at 45° across the graph represents the vapour pressure of pure water. Latent heat of vaporization for the water in the seed can be calculated from the slope of the Othmer plot (Othmer, 1940).

$$\text{slope} = \frac{L}{L_W} = \frac{\log VP_{ST1} - \log VP_{ST2}}{\log VP_{WT1} - \log VP_{WT2}}$$

where L = latent heat of vaporization of water in sample

L_W = latent heat of vaporization of water

VP_{ST1} = vapour pressure sample at temperature 1

VP_{ST2} = vapour pressure sample at temperature 2

VP_{WT1} = vapour pressure of water at temperature 1

VP_{WT2} = vapour pressure of water at temperature 2

The Othmer slopes and latent heats are given in Tables 2 - 5.

The slopes and latent heat increase with decreasing moisture showing the increase in energy required to dry the seed to low moisture levels.

Anomalous readings were found for Target and Arlo at 6% moisture (Table 3).

Slopes of less than one (i.e. less than the slope for pure water) were also found by Haynes (1961) for clover and fescue when using an isotenoscope to measure vapour pressure. He suggested that seed respiration at the higher moisture content limited accuracy. In the high moisture content samples of rapeseed where the dew point was measured in place of the vapour pressure, slope values of slightly less than one were found. The true slopes at the high moisture level are probably very close to that for pure water.

The Othmer slopes for rapeseed and various other seeds are plotted in Fig. 13. The slopes for rapeseed drop more rapidly with increased moisture than for the others. Above 8% moisture the Othmer slope for the rapeseed essentially matches that for water.

Latent heat for the moisture in whole rapeseed is somewhat higher than for that in crushed seed (Tables 2 & 4). Bronowski seed had a higher Othmer slope than the other varieties, about 5 - 10% higher than the whole Echo seed (Table 3).

Table 2

Latent heat of vaporization for water in whole Echo Rapeseed at various moisture content and temperatures, calculated from the Othmer plots.

Moisture Content ¹	Slope (Othmer)	Latent Heat of Vaporization cal/g & (Btu/lb) ²		
		25°C	45°C	60°C
3.58 ₃	1.41	823 (1481)	807 (1452)	795 (1430)
4.03 ₃	1.43	835 (1502)	818 (1473)	806 (1450)
4.55 ₃	1.34	782 (1408)	767 (1380)	755 (1359)
4.93 ₃	1.32	770 (1387)	755 (1359)	744 (1339)
5.05	1.34	782 (1408)	767 (1380)	755 (1359)
6.33	1.20	700 (1261)	687 (1236)	676 (1217)
7.15	1.12	654 (1177)	641 (1153)	631 (1136)

¹Moisture content (% wet basis) measured after testing

²Latent heat of vaporization for water: 1050.4 Btu/lb at 25°C, 1029.8 at 45°C and 1014.1 at 60°C.

Table 3

Latent heat of vaporization of water in four varieties of rapeseed equilibrated at 11% RH and 67% RH

Variety	Moisture ¹ Content	Slope (Othmer)	Latent Heat of vaporization cal/g & (Btu/lb)		
			25°C	45°C	60°C
Target	3.45	1.43	835 (1502)	818 (1473)	806 (1450)
Arlo	3.33	1.45	846 (1523)	830 (1493)	817 (1471)
Oro	3.25	1.47	858 (1544)	841 (1514)	828 (1491)
Bronowski	3.75	1.62	945 (1702)	927 (1668)	913 (1643)
Target	5.95	.89	519 (935)	509 (917)	502 (903)
Arlo	5.98	.90	525 (945)	515 (927)	507 (913)
Oro	6.23	1.12	654 (1177)	641 (1153)	631 (1136)
Bronowski	6.83	1.20	700 (1261)	687 (1236)	676 (1217)

¹Moisture content (% wet basis) measured after testing

Table 4

Latent heat of vaporization for moisture in crushed Echo rapeseed

Moisture ¹ Content	Slope (Othmer)	Latent Heat of Vaporization cal/g & (Btu/lb)			
		15°C	30°C	45°C	60°C
3.68	1.36	801 (1442)	790 (1422)	778 (1401)	766 (1379)
3.98	1.45	854 (1538)	842 (1516)	830 (1493)	817 (1471)
4.23	1.28	754 (1357)	743 (1338)	732 (1318)	721 (1298)
4.55	1.27	748 (1347)	738 (1327)	727 (1308)	716 (1288)
4.55	1.30	766 (1379)	755 (1359)	744 (1339)	733 (1318)
5.33	1.20	707 (1273)	697 (1254)	687 (1236)	676 (1217)
5.68	1.19	701 (1262)	691 (1244)	681 (1226)	671 (1207)

¹Moisture content (% wet basis) measured after testing

Table 5

Othmer Slopes for high moisture content rapeseed

Moisture Content	Othmer Slope
7.0	0.93
9.1	0.97
11.6	0.96
15.8	0.91

4.3 BET Isotherms

BET isotherms have been used by many workers patterned after the work of Brunauer et al. (1938). The data has been plotted in the BET form as $\frac{a}{(1-a)v}$ vs a in Fig. 14 for whole Echo seed. The data fits reasonably to a straight line with a slope $\left(\frac{C-1}{v_m C}\right)$ of 44.39 and an intercept $(1/v_m C)$ of -3.25. This results in values of $C = -12.5$ and $v_m = 0.0244$ g/g dry matter. The monolayer value (v_m) is related to the surface area of the product as: (Labuza, 1968).

$$\begin{aligned} S_o &= V_m \cdot \frac{1}{M_{H_2O}} \cdot N_o \cdot H_2O = 3.5 \times 10^3 V_m \\ &= 3.5 \times 10^3 \times 0.0244 = 85.5 \text{ m}^2/\text{g} \end{aligned}$$

where S_o = surface area m^2/g

V_m = monolayer value g H_2O /g solid

M_{H_2O} = molecular wt H_2O = 18 g/mole

N_o = Avogadro's no = 6×10^{23} molecules/mole

H_2O = area of a water molecule = 10.6×10^{-20} in^2

The area is a bit low although it still appears reasonable. Values between 100 and 250 m^2/g are given by Labuza (1968). The monolayer value for rapeseed ranged from about 70% of the total adsorbed at 3.6% H_2O to about 48% of the total adsorbed at a moisture content of 5%. The actual moisture content of the seed at the monolayer value is quite low and the energy required to reduce the seed to a moisture content below that would appear to be quite high. Brunauer (1938) concluded that the beginning of the approximately linear portion of the sigmoid moisture content vs relative humidity curve (Section 2.1) corresponds to the monolayer coverage value. As calculated above, the monolayer value is lower than any of the experimental data points and as seen in Fig. 5 no inflection point at the lower end of the curve occurs. Further data at moisture contents of 3% and less would be needed to confirm the sigmoid shape.

5.0 Conclusions

Equilibrium relative humidities for rapeseed over the range from 11% to 75% relative humidity were determined. Seed moisture content varied from about 3.5% at the low relative humidity to about 10% at the 75% rh. The values obtained agree very closely with data given by Pichler (1957). Vapour pressure over the seed was determined over a temperature range from 15°C to 60°C for several moisture contents using an isotenscope method. No great differences were observed between the varieties studied, although the equilibrium moisture for Bronowski appeared somewhat higher than for the other four varieties. Othmer plots were used to determine the latent heat of vaporization of water in the seed for various moisture contents. The latent heats at low moisture content were appreciably greater

than for pure water, up to about 40% greater at the 3.5% moisture. Slopes of the Othmer plots drop more rapidly for rapeseed than for the seeds studied by Haynes (1961).

While the data obtained suggests that rapeseed follows a sigmoid curve typical of many food and agricultural products, more points at lower than 3.5% moisture would be necessary to confirm this. The monolayer value calculated from the BET isotherm is at a lower moisture than we have studied. Brunauer (1938) suggests that this monolayer value should correspond to the low moisture inflection point of the equilibrium moisture curve.

6.0 Acknowledgements

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- Agrawal, K.K., Clary, B.L. and Nelson, G.L. 1971. Investigation into the theories of desorption isotherms for rough rice and peanuts. *J. Food Sci.* 36, 919.
- Alam, A. and Shove, G.C. 1973. Hygroscopicity and thermal properties of soybeans. *Trans. ASAE* 16, 707.
- Berry, M.R. and Dickerson, R.W. 1973. Moisture adsorption isotherms for selected feeds and ingredients. *Trans. ASAE* 16, 137.
- Bosin, W.A. and Easthouse, H.D. 1970. Rapid method for obtaining humidity equilibrium data. *Food Technol.* 24, 1155.
- Brunauer, S., Emmett, P.H. and Teller, E. 1938. Adsorption of gases in multimolecular layers. *J. Am. Chem. Soc.* 60, 309.
- Day, D.L. and Nelson, G.L. 1965. Desorption isotherms for wheat. *Trans. ASAE* 8, 293.
- Gay, F.J. 1946. The effect of temperature on the moisture content relative humidity equilibria of wheat. *J. CSIRO* 19, 187.
- Haynes, B.C. 1961. Vapour pressure determination of seed hygroscopicity. U.S.D.A., ARS, Technical Bulletin 1229.
- Henderson, S.M. 1952. A basic conception of equilibrium moisture. *Agr. Eng.* 33, 24.
- Hogan, J.T. and Karon, M.L. 1955. Hygroscopic equilibria of rough rice at elevated temperatures. *Agric. and Food Chem.* 3, 855.
- Hygrodynamics. Creating and maintaining humidities by salt solutions. Technical Bulletin No. 5. Hygrodynamics Inc., 949 Selim Rd., Silver Spring, Maryland 20910.
- Karon, M.L. and Adams, M.E. 1949. Hygroscopic equilibrium of rice and rice fractions. *Cereal Chem.* 26, 1.

- Kilara, A. and Humbert, E.S. 1973. Nitrogen extractability and moisture adsorption characteristics of sunflower seed products. *J. Food Sci.* 37, 771.
- Labuza, T.P. 1968. Sorption phenomena in foods. *Food Technol.* 22, 263.
- Larmour, R.K., Sollans, H.R. and Craig, B.M. 1944. Hygroscopic equilibria of sunflower seed, flaxseed and soybeans. *Canadian Journal of Research* 22, 1
- Legault, R.R., Makower, B. and Talburt, W.F. 1948. Apparatus for measurement of vapour pressure. *Analytical Chem.* 20, 428.
- Othmer, D.F. 1940. Correlating vapour pressure and latent heat data. *Ind. & Eng. Chem.* 32, 841.
- Pichler, H.J. 1957. Sorption isotherms for grain and rape. (translated by W.E. Klinner). *J. Agric. Eng. Res.* 2, 159.
- Richardson, G.M. and Malthus, R.S. 1955. Salts for static control of humidity at relatively low levels. *J. Appl. Chem.* 5, 557.
- Rockland, L.B. 1960. Saturated salt solutions for static control of relative humidity between 5° and 40°C. *Analytical Chem.* 52, 1375.
- Saravacos, G.D. 1969. Sorption and diffusion of water in dry soybeans. *Food Tech.* 23, 1477.
- Smith, P.R. 1971. The determination of equilibrium relative humidity or water activity in foods. A review. The British Food Manufacturing Industries Research Association. Scientific and Technical Survey No. 70.
- Stohman, R.D. and Yoerger, R.R. 1967. A new equilibrium moisture-content equation. *Trans. ASAE* 10, 675.
- Weston, W.J. and Morris, H.J. 1954. Hygroscopic equilibria of dry beans. *Food Tech.* 8, 353.

Wink, W.A. 1946. Determining the moisture equilibrium curves of hygroscopic materials. Ind. Eng. Chem. 18, 251.

Wink, W.A. and Sears, G.R. 1950. Equilibrium relative humidities above saturated salt solutions at various temperatures. TAPPI 33, 96A.

Young, J.H. and Nelson, G.L. 1967. Research of hysteresis between sorption and desorption isotherms of wheat. Trans. ASAE 10, 756.

8.0 Nomenclature

a = water activity = p/P_s

p = water vapour pressure exerted by the material

p_s = vapour pressure of pure water

T = absolute temperature ($^{\circ}\text{K}$)

Q_s = heat of adsorption

R = gas constant

rh = relative humidity

M = equilibrium moisture content (dry basis)

k' } constants in Henderson's equation,
 n } characteristic of the particular material

v = volume absorbed g/g or cc/g }
 v_m = monolayer value } BET isotherm

V_p = vapour pressure

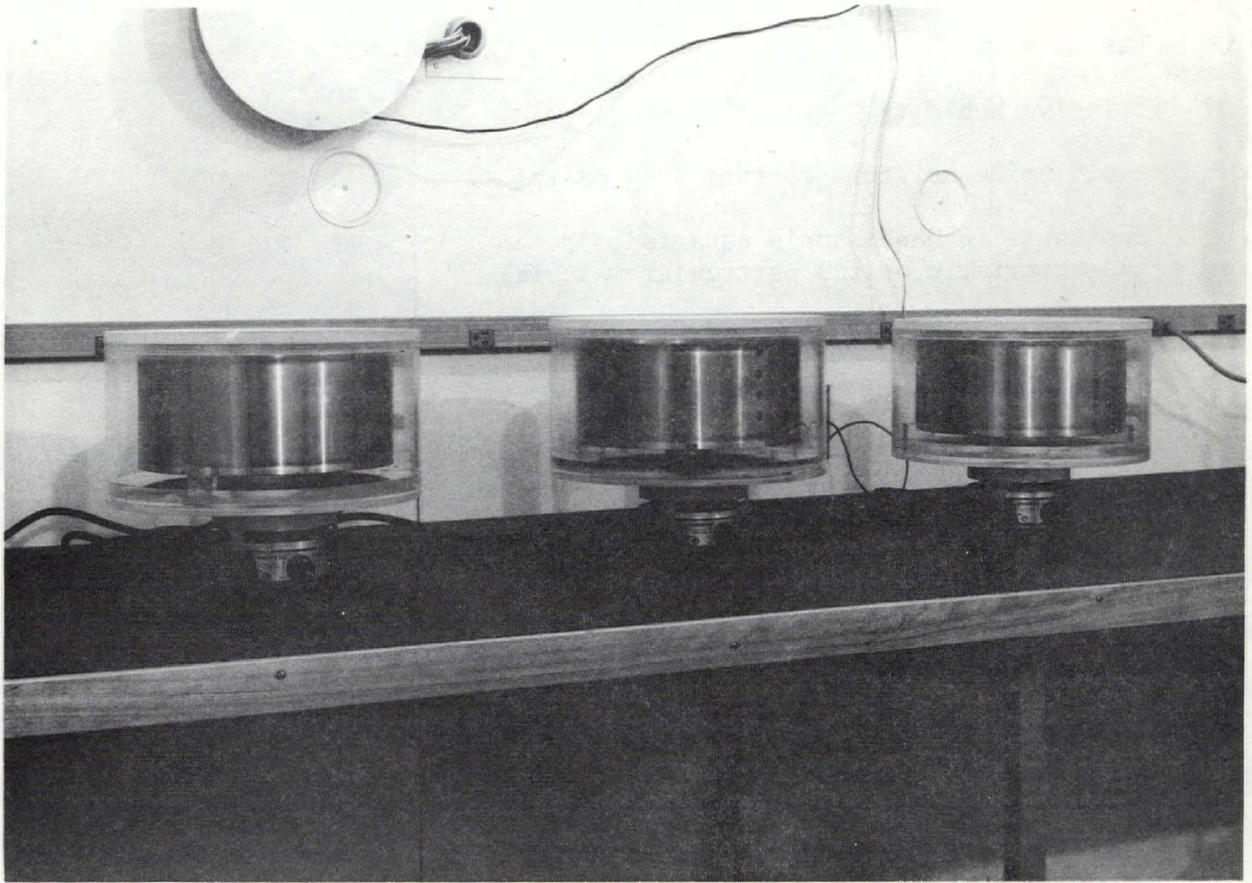


Figure 1. Equilibration chambers with magnetically coupled fans for equilibrating samples above saturated salt solutions.

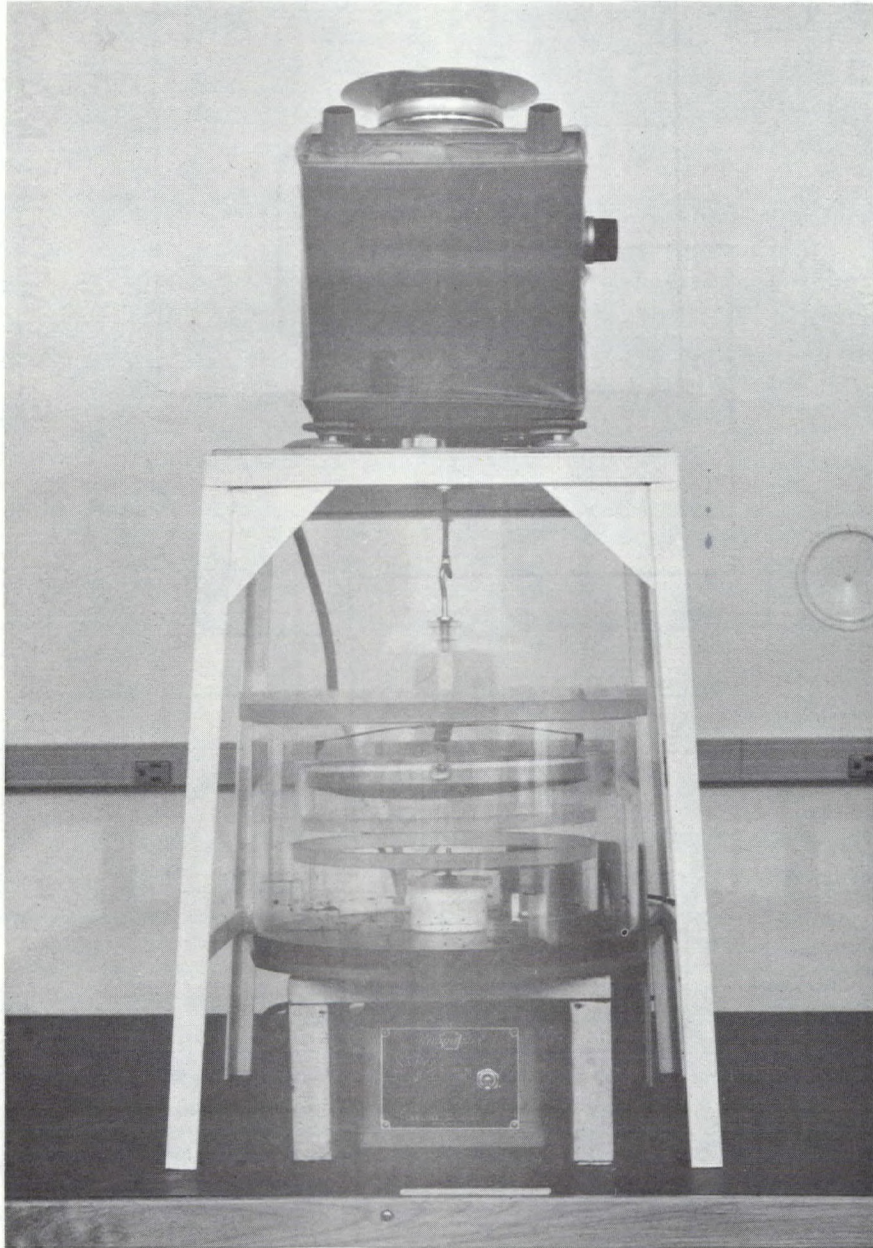
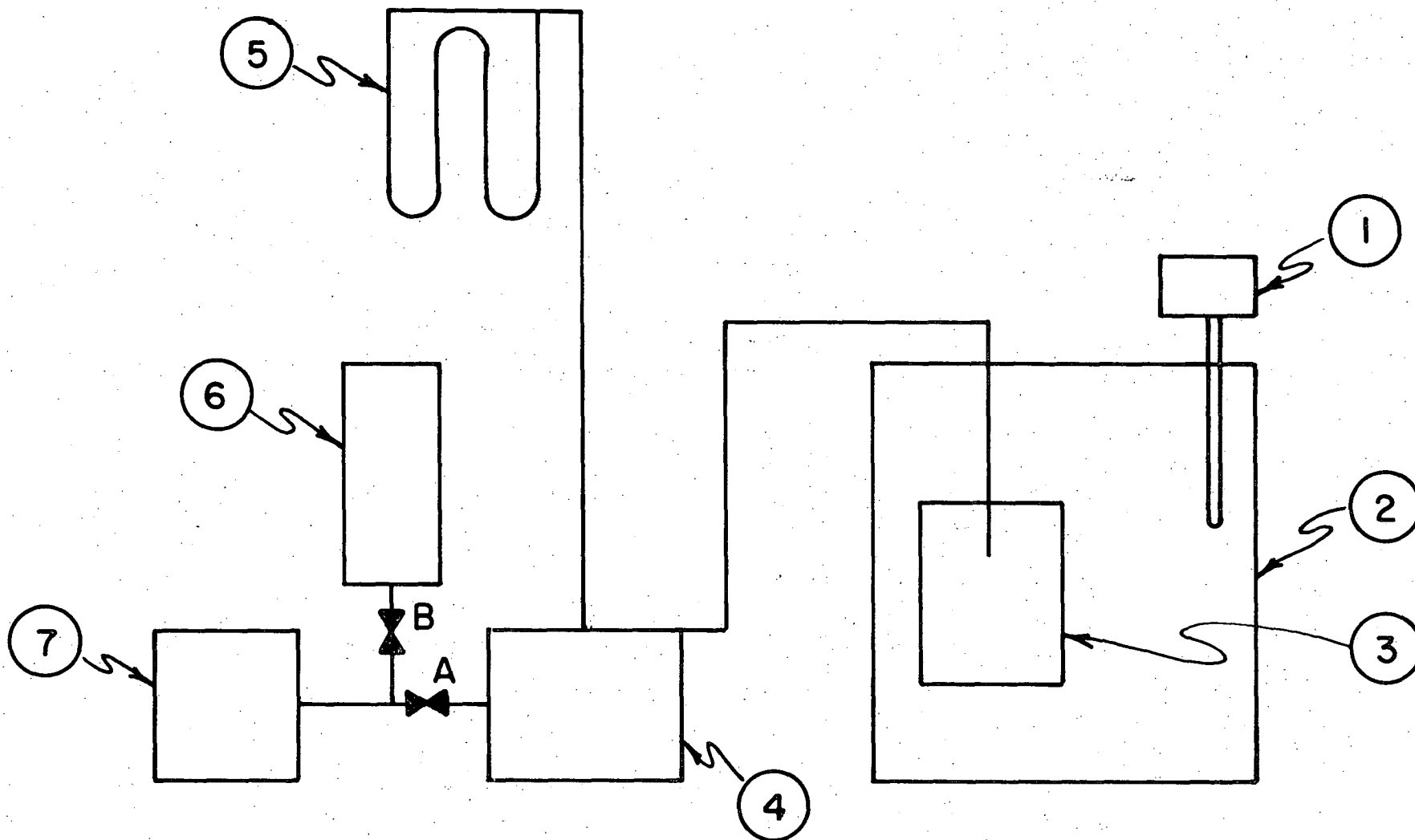


Figure 2. Equilibration chamber with weighing arrangement.

Figure 3. Schematic diagram of isotenoscope assembly.



1. THERMO REGULATOR
2. WATER BATH
3. ISOTENOSCOPE
4. VACUUM STORAGE JAR

5. VACUUM MANOMETER
6. DRIER
7. VACUUM PUMP

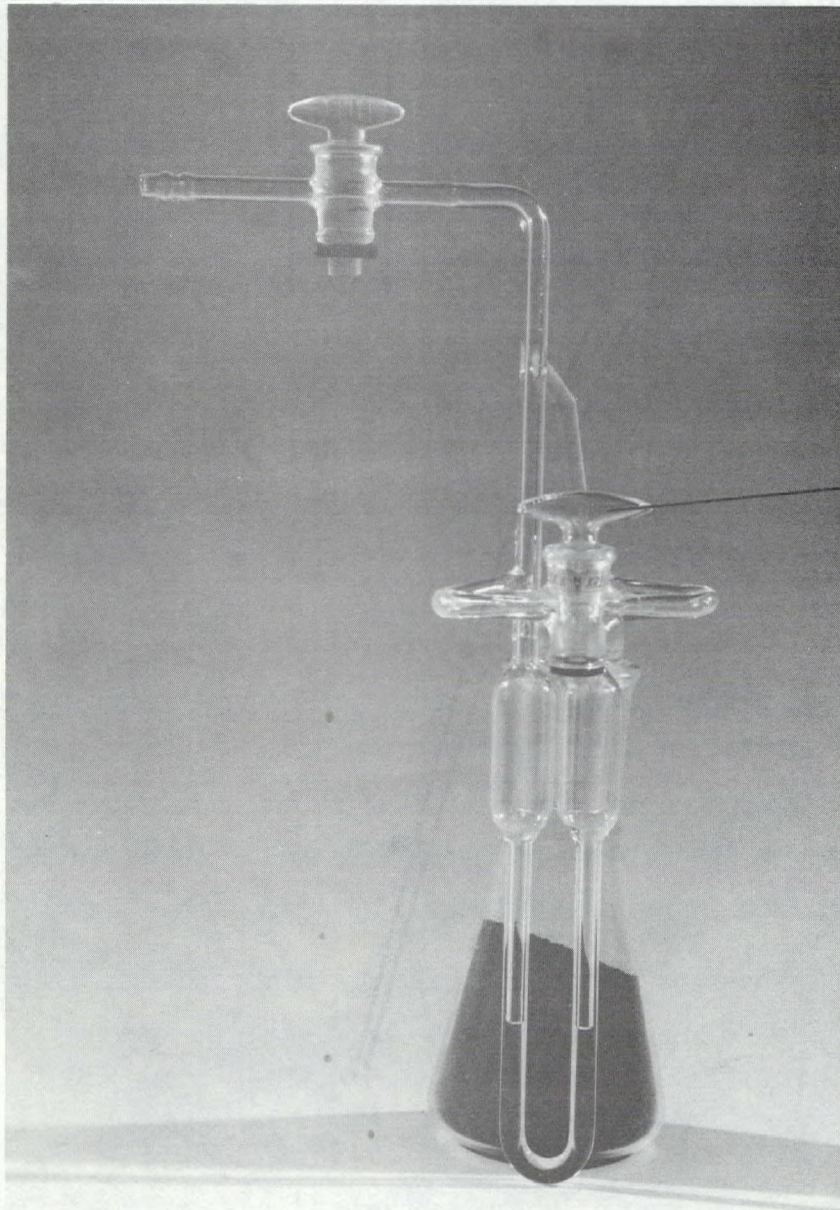


Figure 4. Isotenscope for measuring seed vapour pressure.

Figure 5. Equilibrium relative humidity vs moisture content for whole rapeseed.

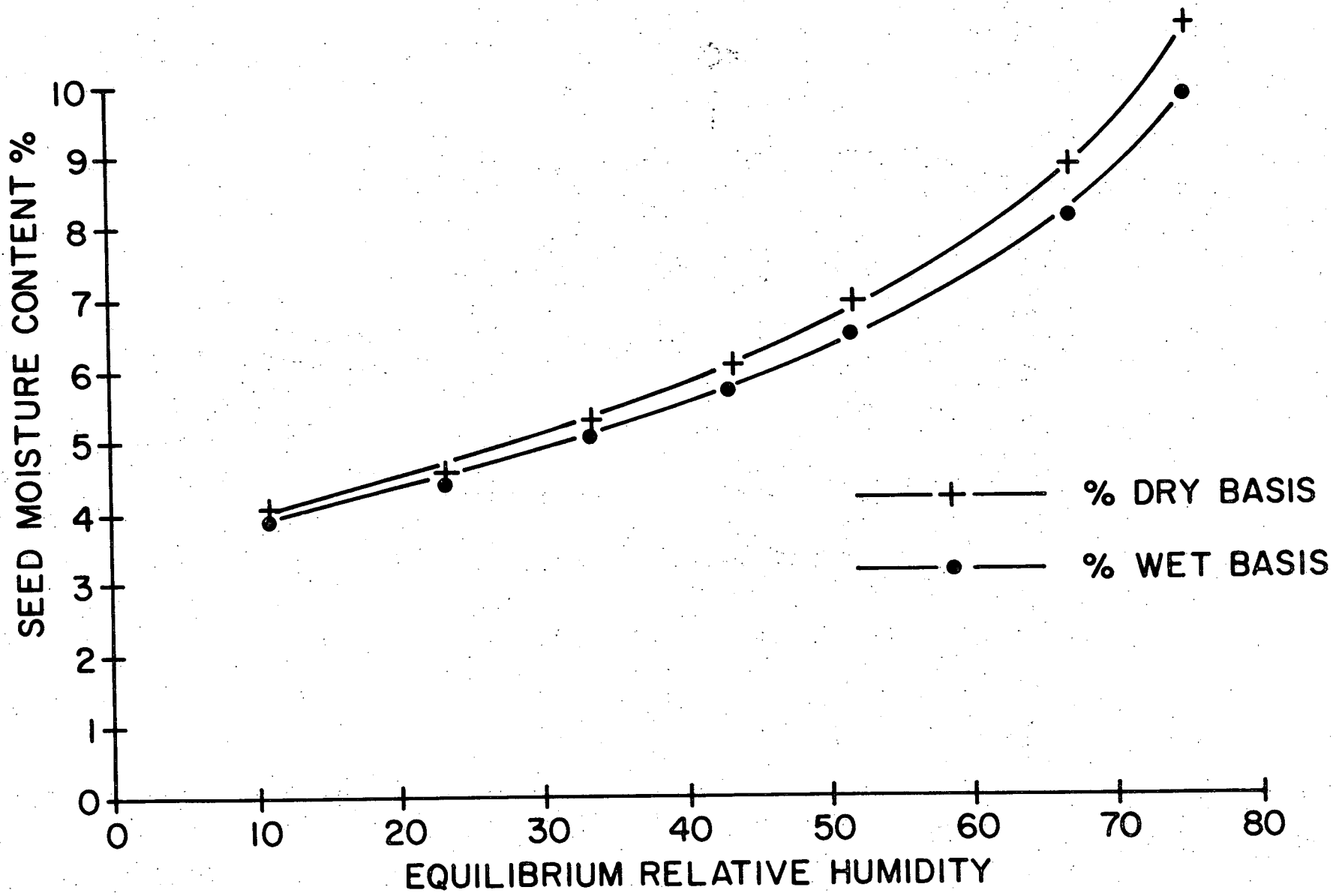
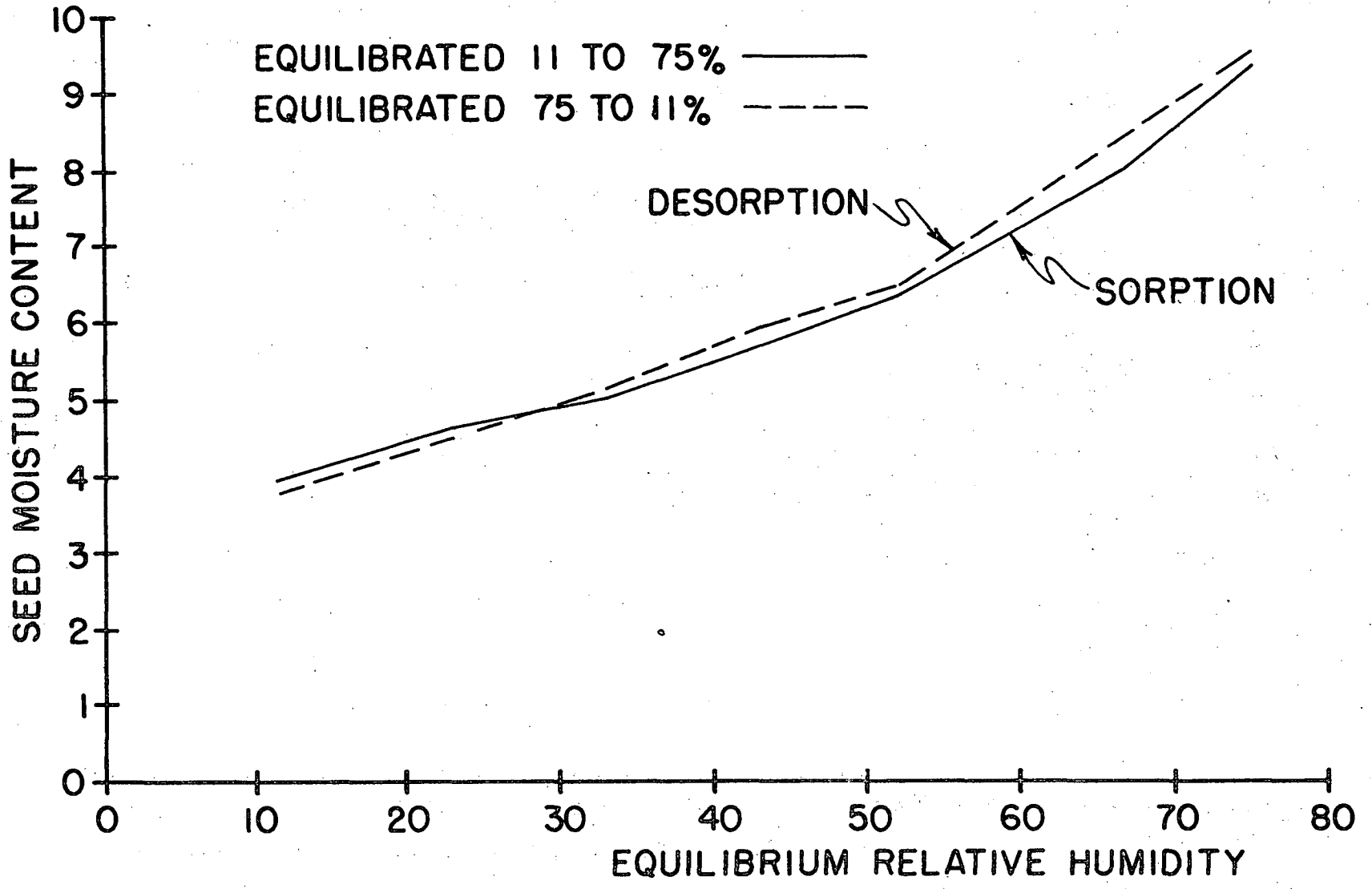


Figure 6. Adsorption and desorption curves for whole Echo rape equilibrated over saturated salt solutions.



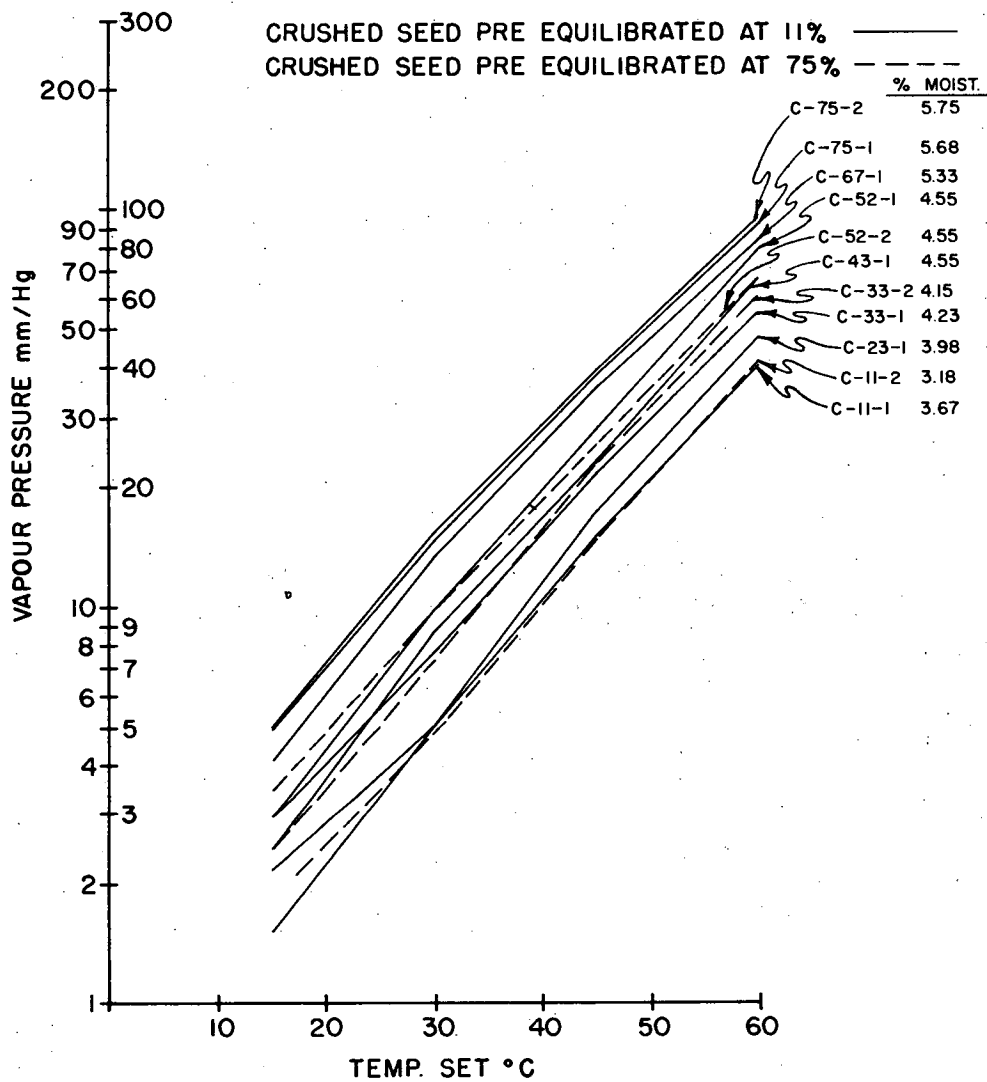


Figure 7. Vapour pressure vs temperature - crushed seed.

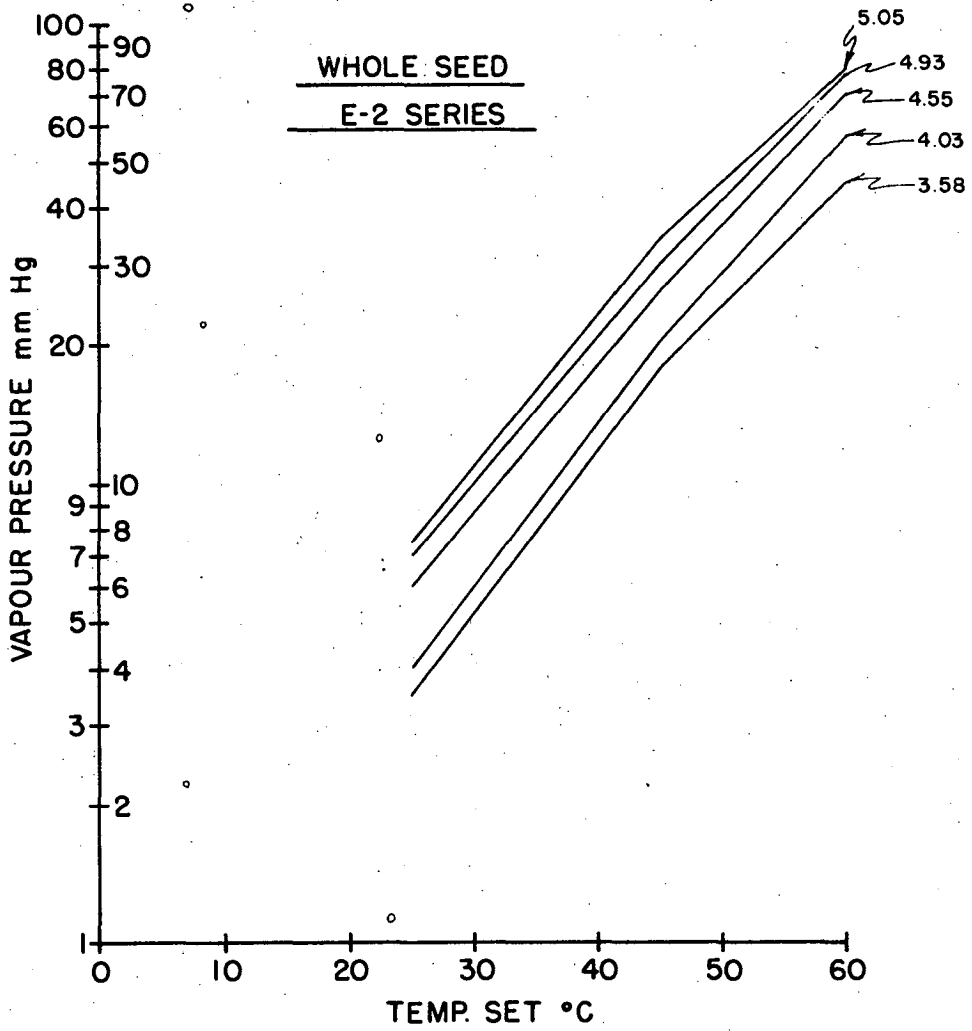


Figure 8. Vapour pressure vs temperature - whole seed.

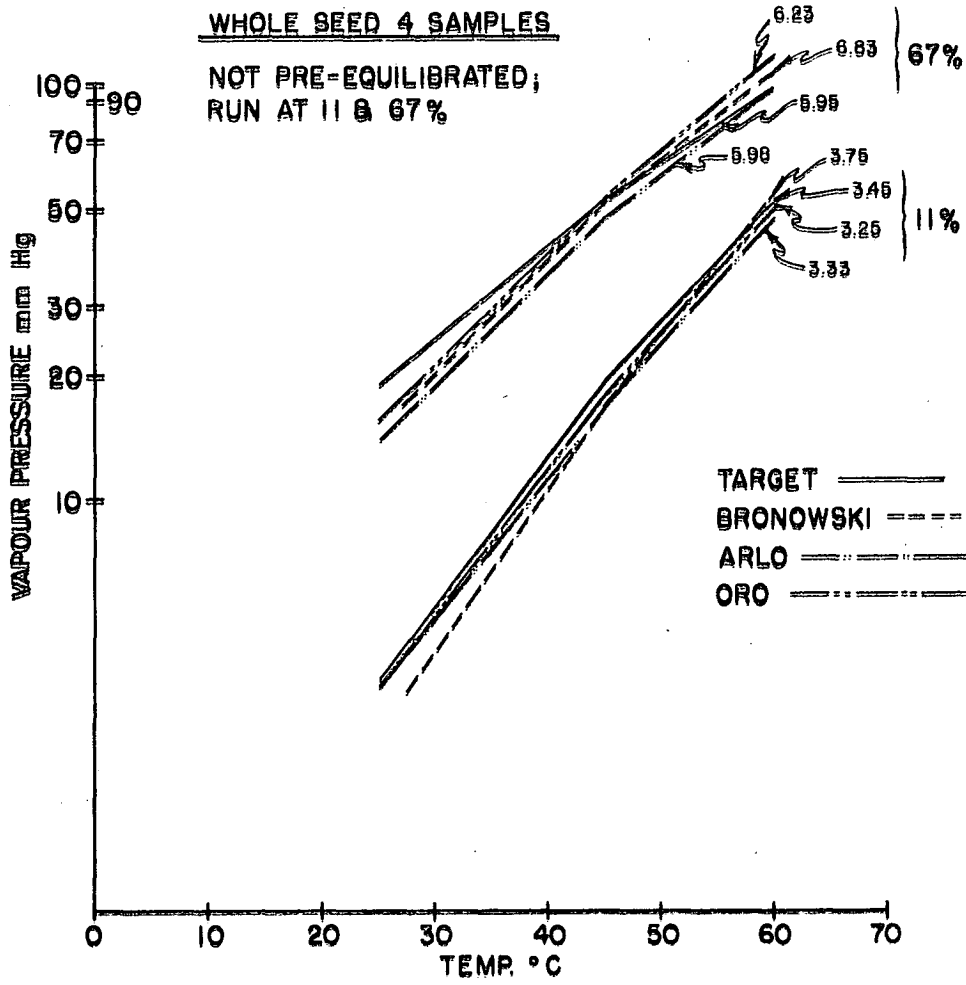


Figure 9. Vapour pressure vs temperature - four varieties.

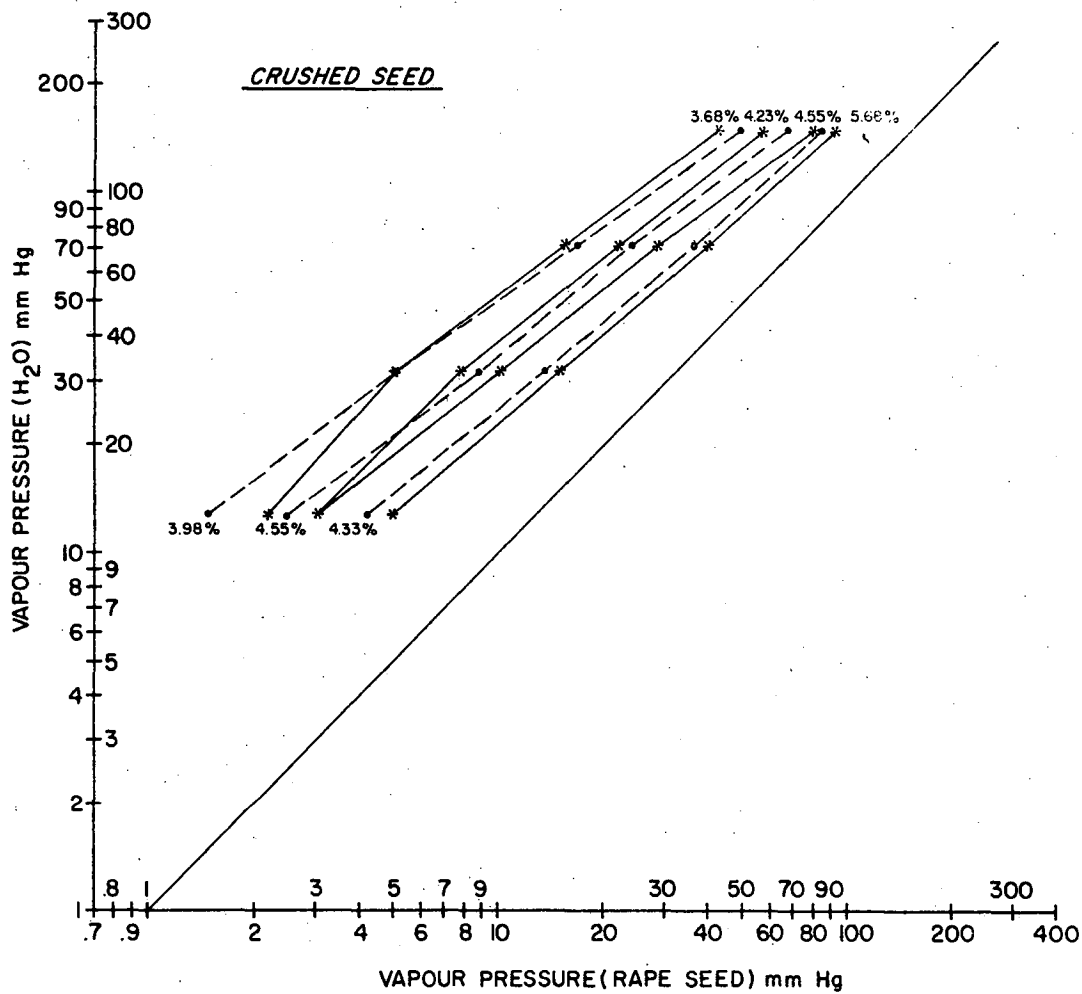


Figure 10. Othmer Plot - crushed Echo rapeseed.

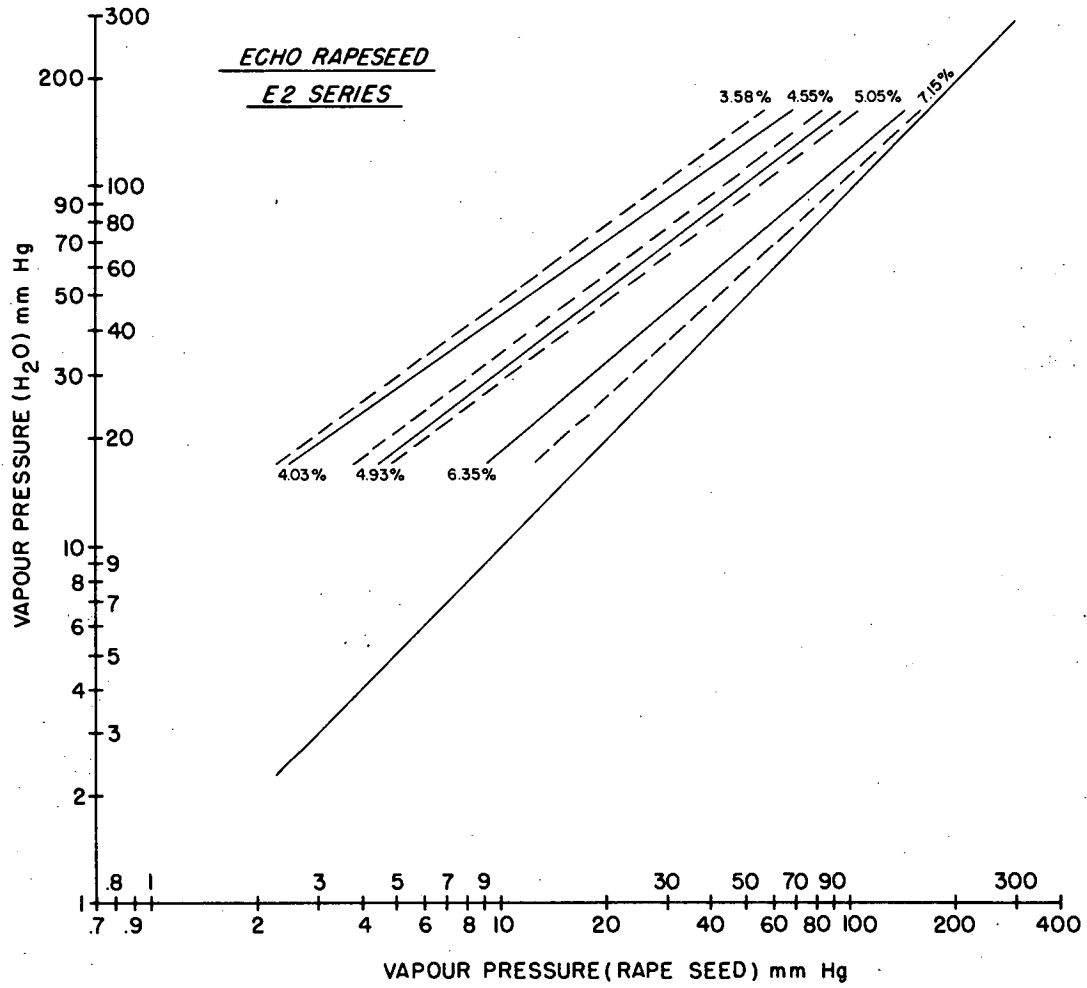


Figure 11. Othmer Plot - whole Echo rapeseed.

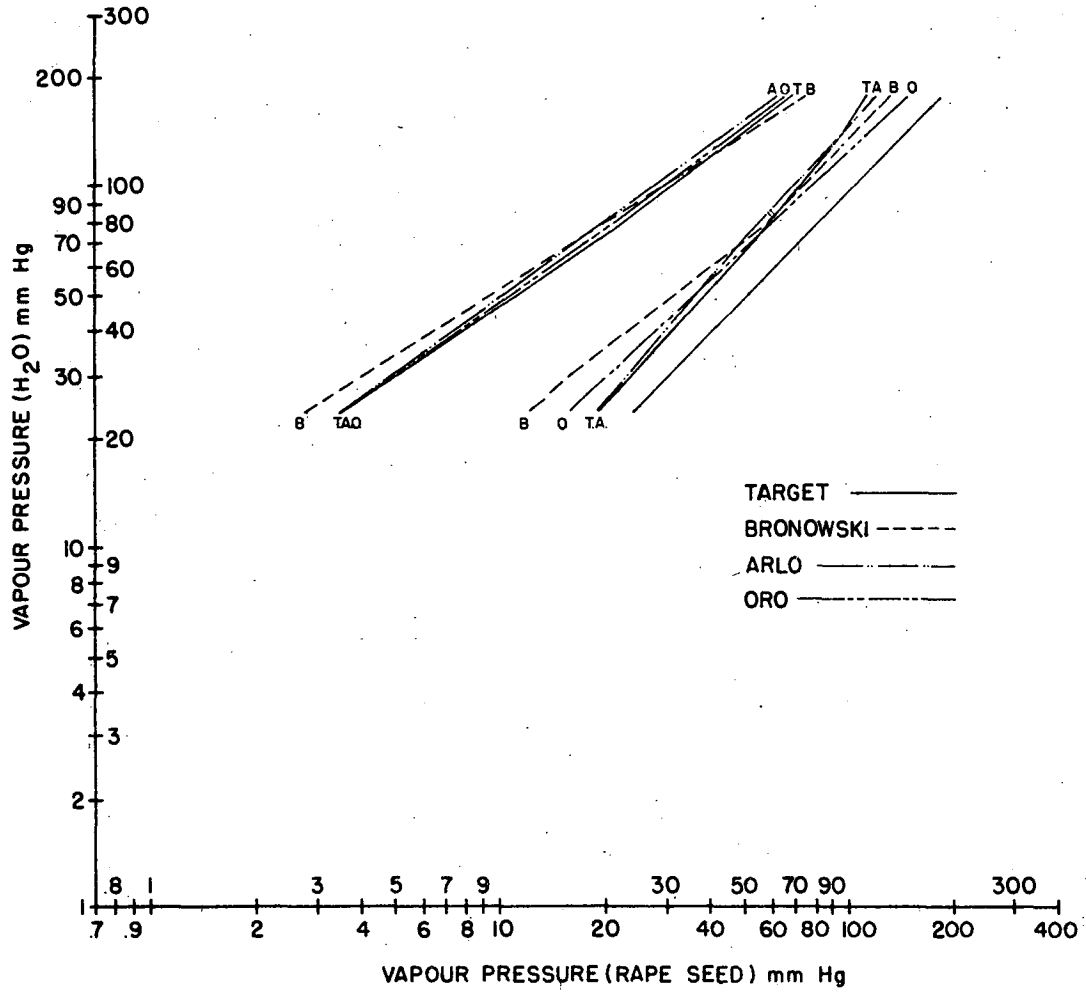
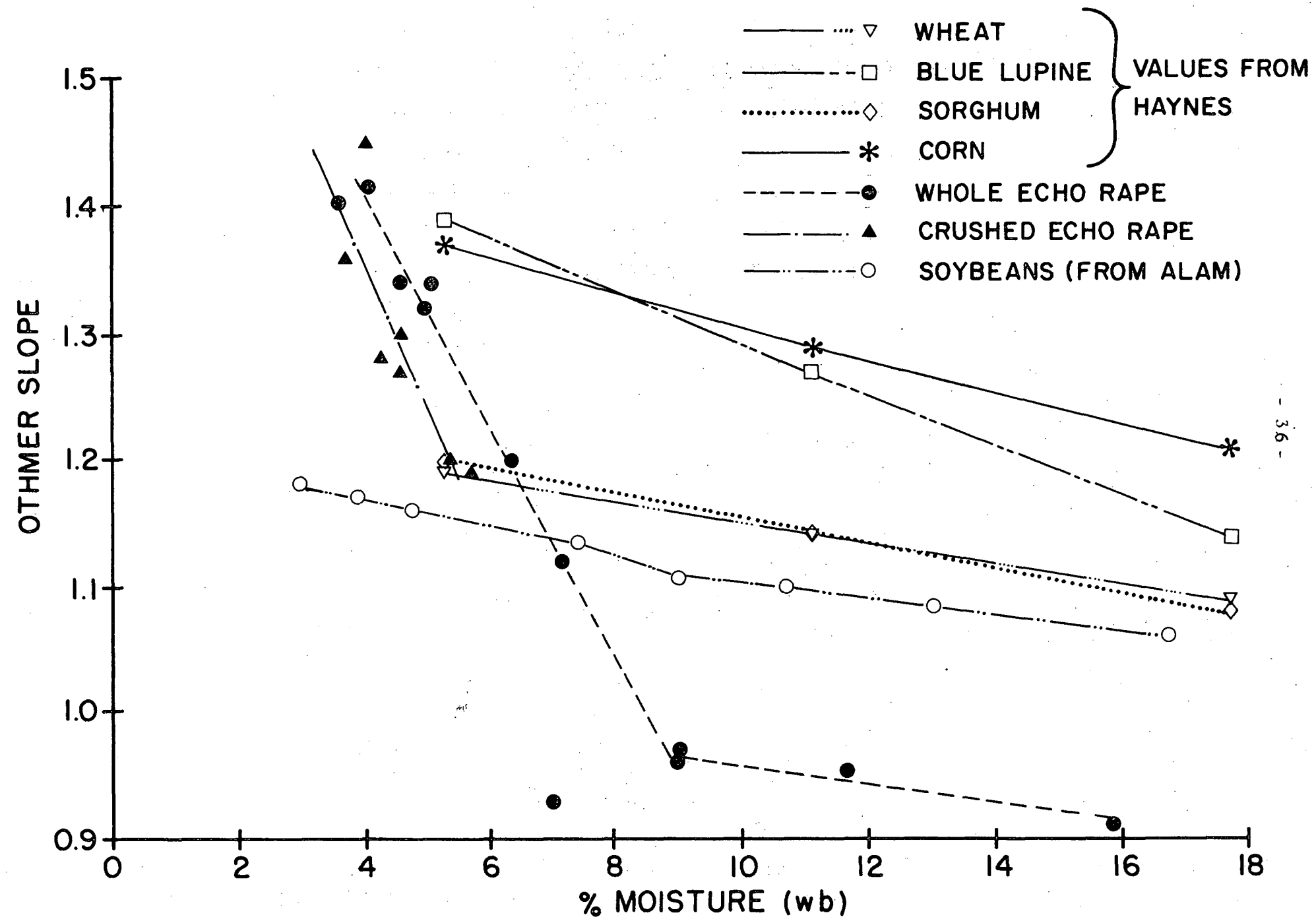


Figure 12. Othmer Plot - four varieties.

Figure 13. Slope of Othmer plot as influenced by moisture content.



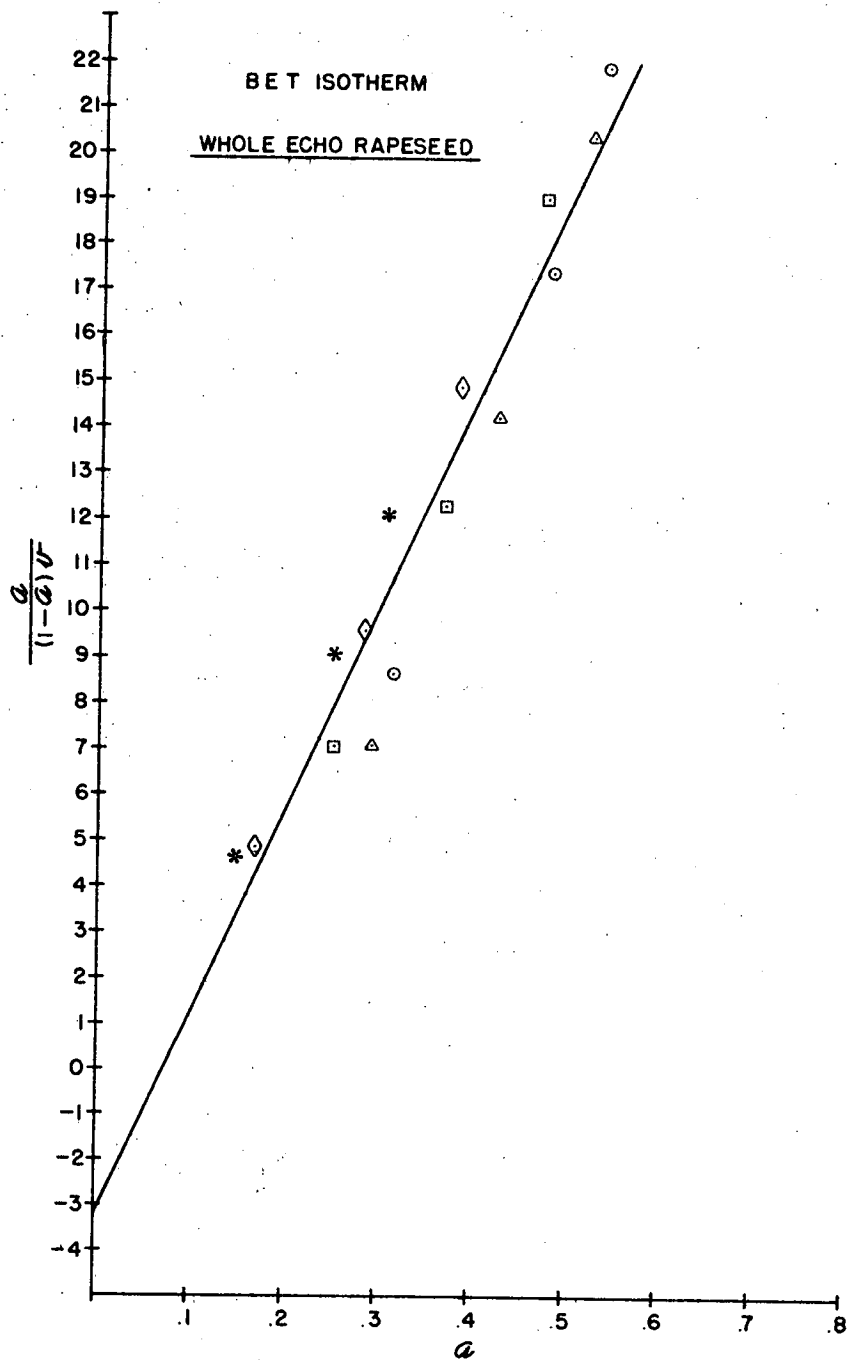


Figure 14. BET isotherm for whole Echo seed.

CAL/BCA OTTAWA K1A 0G5



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