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Tissue Respiration and Body Size[1]

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The relation between tissue respiration and body size has only recently attracted attention, though it is crucial for a classic and major topic of physiology. This relation is decisive for answering the question of whether the systematic decrease of metabolic rate per unit weight with increasing size, which is found in most animal classes and expressed by the so-called surface law and similar formulations, is based upon cellular or organismic factors. After earlier work of Terroine (*1*), Grafe *et al.* (*2, 3*), Kayser *et al.* (*4*), which was inconclusive and contradictory, Kleiber (*5, 6*) investigated the Q_{O_2} of liver from rats, rabbits, and sheep, and Weymouth *et al.* (*7*) the Q_{O_2} of the midgut gland of individuals of different size in the kelp crab *Pugettia*. These workers state a systematic decrease of the Q_{O_2} values with increasing size, in approximately the same extent as basal metabolism of the entire animal decreases. In a recent investigation, Krebs (*8*) compared the Q_{O_2} of 5 tissues of 9 different species. He found that, in general, Q_{O_2} values of the larger species are somewhat lower than the homologous values of small species; but there is no parallelism of this decrease in the different tissues, nor a consistent relation to the decrease of basal metabolic rate per unit weight with increasing size. There seems to be, as yet, no systematic investigation on the intraspecific size dependence of Q_{O_2} of different tissues.

In our experiments, albino rats (Wistar strain) were used, representing a continuous series from newborn animals of 9 g body weight to adults of 392 g.

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TABLE 1

TISSUE METABOLISM AND BODY SIZE IN THE ALBINO RAT

	No. of experiments	Mean Q_{O_2}	Mean Q_{O_2} for body wt 0–50	50–150	150–250	250 +
Heart	33	9.09 ± .49	10.68	8.48	8.45	7.93
Lung	35	7.15 ± .25	7.90	6.50	6.93	6.34
Liver	49	8.62 ± .22	9.03	9.08	7.20	7.55
Kidney	48	15.50 ± .36	15.70	14.19	16.42	16.85
Brain cortex	30	8.62 ± .25	8.25	8.70	8.35	9.92
Thymus	32	8.25 ± .33	9.04	8.75	7.06	6.99
Diaphragm	26	6.26 ± .51	8.99	6.08	4.75	4.87

The Q_{O_2} ($\mu l O_2$/mg dry wt/hr) of heart, lung, kidney, liver, brain, thymus, and diaphragm was determined by the Warburg method. The tissue slices were taken from animals under basal metabolism regime (10–18 hr fasting). Respiration was measured in Krebs-Ringer phosphate solution (pH, 7.4) and in an atmosphere of oxygen. Higher Q_{O_2} values can be obtained in other media; but this was considered to be immaterial for the present purpose, which amounts to a comparison under standard conditions. There was no decline in the intensity of respiration during the experimental period (1 hr) except in brain tissue. The total number of determinations presented here is 253.

The order of the differences to be expected if the decrease of basal metabolic rate is based upon differences in tissue respiration can be estimated as follows. It appears that the surface rule holds intraspecifically for the rat (*9*); this is also stated by Kleiber (*10*), according to Benedict's data (*11*). Then

$$M = bW^{2/3}, \tag{1}$$

if M is the rate of basal metabolism, W the body weight, and b a constant; and correspondingly

$$\frac{M}{W} = bW^{-1/3} \tag{2}$$

for metabolic rate per unit weight. If, for example, the weights compared are 1 : 2 : 4 : 8 : 16, metabolic rates per unit weight (a measure of which is Q_{O_2}) should decrease in the ratio 1 : 0.79 : 0.63 : 0.50 : 0.4. Such differences should be easily detected by the Warburg method. We would not expect that the rate of decrease of Q_{O_2} with increasing size is the same in all tissues, but even then significant differences of the Q_{O_2} values should be found.

Actually, we did not find in our experiments systematic differences which would account for the decrease of the rate of total metabolism with increasing size (Table 1). A slight decrease in the average Q_{O_2} values is noticeable in some tissues (liver and heart) and especially in the diaphragm. But it is definitely smaller than the extent postulated by the surface rule, and not systematic with respect to the various tissues. Also if, instead of the surface rule, the 3/4 power of

weight, recommended by Kleiber and others as "metabolic unit of body size," should be adopted, these conclusions are not altered.

Our results, obtained in intraspecific comparison, correspond to the results of interspecific comparison obtained by Krebs (which came to our attention only after the beginning of our study). The experiments seem to be a blow to the hypothesis that the decrease of basal metabolic rates with increasing size is due to cellular factors, as expressed by Weymouth *et al.* (*7*): "The regressions of the weight-specific rates for the different tissues apparently form, in the log-log plot, a family of parallel lines, some higher and some lower, corresponding to the intensity of respiration, but all showing the same slope as the regression of the weight-specific rate of the entire animal" (p. 68). None of these statements is substantiated by our experiments. It appears that the main regulative principle responsible for the systematic decrease of weight-specific basal metabolic rate with increasing size must be sought in factors lying in the organism as a whole.

A full presentation of the data obtained will be given elsewhere.

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Effect of Germination on the Carotene Content of Pulses and Cereals

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In our studies on the effect of germination on the vitamin content of pulses we have observed increased formation of ascorbic acid (*1, 2*), nicotinic acid (*3*), thiamine (*4*), and riboflavin (*5*), in different varieties of pulses during the process. In the present communication the effect of germination on the carotene content of different pulses and cereals is presented.

Five g of healthy dry seeds of pulses were germinated with distilled water in clean Petri dishes, which were kept away from direct sunlight. In the case of cereals, the seeds were embedded in earth soaked with water in Petri dishes for proper germination. After germination for varying periods the seeds were crushed. Carotene was extracted by the method of Guilbert (*6*), as modified by Peterson, Hughes, and Freeman (*7*), and estimated with a Lumetron photoelectric colorimeter using a 440-mμ filter. The results are shown in Tables 1 and 2.

TABLE 1

EFFECT OF GERMINATION ON THE CAROTENE CONTENT OF PULSES

Local name	Botanical name	Days of germination				
		0	1	2	3	4
		Mg/100 g of pulse				
Krishna mung	*Phaseolus radiatus*	3.75	4.35	4.40	4.70	4.75
Musuri	*Lens esculenta*	1.60	1.60	2.00	3.90	4.05
Hara chhola	*Cicer arietinum*	3.10	3.80	4.00	4.20	4.50
Golapi chhola	" "	1.95	2.10	2.40	2.75	3.00
Chhola	" "	2.95	3.35	4.20	4.30	4.35
Mung	*Phaseolus radiatus*	2.15	3.60	3.75	3.80	3.80
Barbati	*Vigina sineusis*	0.70	1.40	1.50	1.60	1.55
Pyra mator	*Pisum sativum*	1.50	1.60	2.00	2.25	2.30
Sona mung	*Phaseolus aurus roxburgi*	2.35	2.95	3.25	3.10	3.15
Kalai	*Phaseolus mungo*	1.25	1.68	1.85	2.10	2.30
Mas kalai	*Phaseolus roxburgi*	1.75	2.10	2.75	2.80	2.80
Kabuli chhola	*Cicer arietinum*	2.05	2.95	3.45	4.15	4.30
Pea	*Pisum sativum*	1.20	1.35	1.50	1.75	2.35

TABLE 2

EFFECT OF GERMINATION ON THE CAROTENE CONTENT OF CEREALS

Cereal	Days of germination							
	0	1	2	3	4	5	6	7
	Mg/100 g of cereal							
Paddy (*Oryza sativa*)	0.35	0.40	0.75	1.35	2.15	2.85	3.25	3.95
Wheat	0.45	0.43	0.70	1.50	2.25	3.25	4.50	4.65
Corn	4.00	4.00	4.35	4.95	5.25	5.75	5.95	6.15

Pulses contain a good amount of carotene in the dry condition. Paddy and wheat, however, do not contain much carotene, whereas corn is a rich source of carotene in the dry condition. In all cases, the carotene content increased considerably as the germination proceeded. In cereals, on the first day of germination there is not much change in the carotene content, probably because the seeds do not sprout well. But as the shoots develop the carotene content increases gradually. After the third day of germination the color of the shoots is changed from yellow to green, which probably indicates that chlorophyll and other plant pigments increase during germination; carotene being a pigment, also, increases simultaneously with the other pigments. From the results obtained it is clear that the rate of increase in the carotene content of both pulses and cereals depends on the rate of growth of their seedlings. Pulses form an important ingredient in the Indian diet. The germinated pulses are, therefore, nutritionally superior to the unger-