Air passage capacity in leaves

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INTRODUCTION

Stomata are of great importance for gas exchange in plant. They exercise control by opening or closing. Microscopic investigation of stomatal movements is most correct but rather difficult and is restricted to a narrow areas of the leaf.

Porometric methods were introduced early. Darwin and Pertz (1911) constructed the first porometer. They recorded the velocity of penetration of air sucked through the leaf blade. Another type of porometer was constructed by Gregory and Pearse (1934). They measured the relative resistance of the leaf against the air stream. Other porometers resembled the first or the second type with the exception of diffusion porometer (Gregory and Armstrong 1936), differential porometer (Meidner and Spanner 1959) and De Alvim's one mentioned by Shimshi (1963).

APPARATUS*

The simple porometer consists of clinical tongs with the toothed lock and is provided with two brass cups and micromanometer (Fig. 1). The border of each cup is fitted with rubber to assure tight closure of the leaf blade between the cups. The borders of the cups squash the tissue around the part of the leaf closed in the porometer, therefore the air exchange with other parts of the leaf seems to be interrupted completely.

This porometer is for application in amphistomatal leaves only; such leaves are common especially in cultivated plants. Each cup is provided with an air hole. The air is released from a special bottle under a little pressure and conducted through a rubber tube to the upper cup; it penetrates the leaf blade and escapes to the outside through the lower cup. A small rinsing vessel containing some water indicates the presence and the velocity of the air stream. It is sufficient to enclose a leaf in the

* This porometer was constructed in September 1963, and demonstrated during the Symposium on water stress in Prague on 2nd of October 1963, and during the Tenth International Botanical Congress (1964) in Edinburgh.

Fig. 1 The porometer.

Fig. 2 The porometer in action.

porometer for even twenty seconds to be able to ascertain the pressure necessary to cause the air to flow through the leaf blade (Fig. 2).

The preliminary investigations conducted in September 1963 showed that under the natural growth conditions in the light a very small (a few mm Hg) pressure was sufficient to cause a quick air stream visible in the water rinse. If detached leaves were kept in the dark for one or two hours even a pressure of 50 or 100 mm Hg did not cause the air to flow through the leaf or else the air stream was barely visible.

A special apparatus (Fig. 3) for measuring the amount of air flowing through was used in subsequent investigations. It consisted of a water reservoir and burette filled with water. The water in the burette is gradually replaced by air. When a measurement is completed the reser-

Fig. 3 The apparatus for measuring the amount of air flowed through the leaf.

voir (flask) is turned upside down and the burette is refilled for the next reading. A water manometer was used instead of the medical manometer for more precise investigations. The complete set-up is presented in Fig. 4.

A.P.C. — index

The amount of air passing through the leaf is proportional to the pressure difference and inversely proportional to the resistance presented by the leaf. This can be expressed by the simple equation:

$$V = \frac{P}{r} \quad (1)$$

where V denotes cm^3 air passing through 1 cm^2 of the leaf blade during

Fig. 4 The complete set-up in action.

1 minute, P denotes the difference in pressure between the upper and the lower leaf blade surface expressed in eg. millibars, and r denotes the resistance presented by stomata particularly when they are partially open and by the leaf tissues through which the air passes (intracellular spaces).

According to Poiseuille's law gases and liquids flow through a tube at rate proportional to the fourth power of the opening radius.

Darwin and Pertz (1911) measured V values at nearly constant pressure (suction). Gregory and Pearse (1934) measured the resistance (r). In the present method the velocity of air flow (V) and the pressure (P) are measured simultaneously (the pressure may vary). Knowing V and P , r or its reciprocal may be calculated. By carrying P to the left hand side of equation (1) we obtain:

$$\frac{V}{P} = \frac{1}{r} \quad (2)$$

In electricity the reciprocal of resistance is known as conductivity. By way of analogy the reciprocal of leaf resistance shall henceforth be called "air passage capacity" (APC). If V is expressed in $\text{cm}^3 \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$

and P is expressed in milibars (mb), APC will be expressed in $\text{cm} \cdot \text{min}^{-1} \cdot \text{mb}^{-1}$ and will be simply the linear rate of air flow through the leaf under the pressure of 1 mb.

PRELIMINARY APC MEASUREMENTS

The APC value is independent of pressure. Tests carried out using radish and rape confirmed that in agreement with Poiseuille's law the rate of air flow through the leaf (V) is proportional to the pressure and when expressed as relative to 1 mm Hg or to 1 mb it is a constant ($V/P = \text{const.}$) (Table 1 and 2). APC values are expressed relative to 1 cm^2 of leaf blade surface. The porometer cup covered 5 cm^2 of the leaf surface so that the V/P value had to be divided by 5. Pressure expressed in mm Hg was converted to mb by multiplying by 1.33.

When the leaf is held in porometer there is a decrease in APC value connected with closure of the stomata. (Tabl. 3, 4, 5).

Table 1

APC values at different pressure in radish leaf

Pressure P mmHg	Air flow V ml/min.	Relation V/P	APC value cm/min.mb
5	5	1.0	0.26
10	10	1.0	0.26
15	14.3	0.95	0.25

Table 2

APC values at different pressure in rape leaf

Pressure P mmHg	APC value	Pressure P mmHg	APC value	Pressure P mmHg	APC value
10	.16	10	.145	15	.13
10	.16	10	.14	20	.13
10	.16	10	.14	20	.125
15	.145	10	.14	30	.125
15	.145	10	.135	30	.120
10	.145	10	.135		

Shutting of the stomata may be a fast process and the APC value may decrease five-fold within 30 minutes (Tab. 4). Further investigations will be conducted concurrently with microscopic observations according to the method of M. G. Stålfelt (1929) which seems to be the most convincing and precise one.

Table 3

APC values in rape leaves at different lighting conditions

A - Leaves from plants cultivated at a light intensity of about 7000 lux.		B - Leaves from plants which were kept in dim light for 3 hours	
Leaf	cm/min.mb	Leaf	cm/min.mb
1-st	4.1	1-st	0.63
2-nd	4.2	2-nd	0.71
3-rd	4.3	3-rd	1.11
		4-th	0.24

Table 4

Changes in APC values with time when
the leaf in the porometer was kept in the dark

Rape Successive tests	
Test every 1 minute cm/min.mb	Test every 5 minutes cm/min.mb
1.01	0.32
0.89	0.31
0.73	0.26
0.59	0.19
0.50	0.18
0.43	

Table 5

Changes in APC values with time when the leaf
in the porometer was kept in the dark

Sugar beet	
Time	APC value cm/min.mb
11 ^h 07 ^m	0.15
11 30	0.12
12 00	0.04
12 30	0.02
13 00	0.01
16 00	0.005

SUMMARY

A very simple porometer for use in amphistomatal leaves is described. Both pressure and the rate of air flow in cm^3 per 1 cm^2 leaf blade were measured and a concept the „air passage capacity” (APC), being the reciprocal of leaf resistance, was evolved. It is the linear rate of air flow through the leaf under the pressure of 1 mb. APC is expressed as $\text{cm.mn.}^{-1} \cdot \text{mb}^{-1}$. The APC value is independent of pressure but varies considerably depending on whether the leaf is kept in the light or in the darkness — depending on stomatal movements.

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Gazowa przelotowość liścia

Streszczenie

Przedstawiono bardzo prosty typ porometru dla liści amfistomatycznych. Z wysokości użytego ciśnienia i szybkości przepływu powietrza przez blaszkę liściową wynika nowe pojęcie „przelotowości liścia” — jest to szybkość liniowa z jaką powietrze płynie pod ciśnieniem 1 milibara. Jednostką przelotowości jest $\text{cm} \cdot \text{min}^{-1} \cdot \text{mb}^{-1}$. Przelotowość stanowi odwrotność oporu jaki stawia liść względem przepływającego powietrza. Jest to jednostka bezwzględna w układzie c.g.s. Przelotowość zależy wyłącznie od budowy anatomicznej liścia, od liczby aparatów szparkowych przypadających na 1 cm^2 powierzchni i stopnia ich rozwarcia. Na podstawie kilku doświadczeń przedstawiono zmiany przelotowości pod wpływem światła i zaciemnienia u liści rzodkiewki, rzepaku i buraka cukrowego.