POD-PPO state-dependent correlation as an adaptation indicator in the vegetation of forest trees

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Summary – The correlation of biochemical variables and the regression of their values are very sensitive to physiological state alterations that make them be suitable for the characterization of the interaction between the plant and its environment and for the indication of plant adaptation ability, respectively. The concept of state-dependent correlation applied for the activities of peroxidase (POD; EC 1.11.1.7) and polyphenol oxidase (PPO; EC 1.10.3.1) was used to monitor the vegetation period of some forest trees. The POD and PPO activities of leaf extracts from Penduncular oak (*Quercus robur* L.) and beech (*Fagus sylvatica* L.) trees provided linear correlation. Parameters of their state-dependent regressions have been established to be susceptible to the environmental conditions. Comparing the state-dependent regressions belonging to various sampling times to each other, deterministic alterations of POD-PPO regression are revealed that can be related to the alterations of temperature, relative humidity and global solar radiation. Beside the conservation of high values of the coefficient of determination (R^2), the vegetation sequence of the state-dependent regressions and the alterations experienced in those ones can be considered a consequence of the adaptation in the plant ecological system.

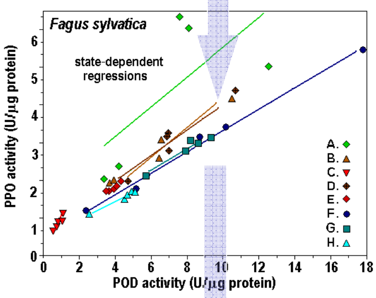
PRIMARY DATA

Table 1-2. POD and PPO activities (U/µg protein) in the vegetation period and their statistic parameters (SD – standard deviation; CI - confidence interval; R^2 – coefficient of determination)

Sampling	Beech	1	2	3	4	5	Mean	SD	± CI	Slope	Intercept	R^2
(A) 15 May	PPO	6.144	6.493	5.029	2.034	2.382	4.416	2.091	2.618	0.395	1.586	0.4720
	POD	7.995	7.720	12.543	3.389	4.203	7.170	3.639	4.556			
(B) 30 May	PPO	3.064	2.574	1.963	4.173	1.922	2.739	0.930	1.164	0.340	0.617	0.9684
	POD	6.554	6.482	3.974	10.437	3.776	6.245	2.692	3.370			
(C) 12 June	PPO	0.656	0.757	0.933	1.125	0.905	0.875	0.179	0.224	0.887	0.116	0.9573
	POD	0.585	0.771	0.965	1.109	0.853	0.857	0.198	0.248			
(D) 26 June	PPO	2.762	3.147	1.966	4.378	3.258	3.102	0.875	1.095	0.396	0.236	0.9434
	POD	6.993	6.932	4.668	10.646	6.979	7.243	2.147	2.689			
(E) 17 July	PPO	1.840	1.714	1.777	1.983	1.706	1.804	0.114	0.143	0.336	0.508	0.9351
	POD	3.988	3.483	3.875	4.332	3.639	3.864	0.328	0.411			
(F) 31 July	PPO	5.459	3.405	1.178	3.122	1.775	2.988	1.662	2.081	0.283	0.489	0.9939
	POD	17.811	10.132	2.404	8.685	5.144	8.835	5.858	7.335			
(G) 14 Aug	PPO	2.994	3.134	2.153	2.795	3.059	2.827	0.397	0.497	0.281	0.591	0.9391
	POD	8.593	9.357	5.699	7.987	8.191	7.966	1.371	1.717			
(H) 28 Aug	PPO	1.469	1.113	1.689	1.676	1.601	1.510	0.239	0.299	0.223	0.539	0.9628
	POD	4.507	2.52	4.929	5.104	4.718	4.355	1.050	1.315			

Sampling	Oak	1	2	3	4	5	Mean	SD	± CI	Slope	Intercept	R^2
(A) 15 May	PPO	2.538	2.045	2.105	3.300	7.028	3.403	2.088	2.614	0.376	-0.632	0.9854
	POD	9.507	6.754	6.656	10.635	20.082	10.727	5.508	6.898			
(B) 30 May	PPO	2.099	2.568	3.179	3.045	5.943	3.367	1.502	1.881	0.285	0.915	0.9709
	POD	4.476	5.357	9.333	6.537	17.287	8.598	5.191	6.500			
(C) 12 June	PPO	1.437	1.577	2.228	1.430	4.829	2.300	1.451	1.817	0.315	0.408	0.9972
	POD	3.489	3.970	5.546	2.985	14.068	6.011	4.605	5.766			
(D) 26 June	PPO	5.253	5.657	7.474	7.237	8.677	6.86	1.401	1.754	0.295	2.051	0.9946
	POD	10.656	12.212	18.389	18.129	22.075	16.292	4.733	5.927			
(E) 17 July	PPO	2.205	3.552	2.133	2.993	2.517	2.680	0.593	0.743	0.395	0.156	0.9812
	POD	5.096	8.714	5.166	6.866	6.130	6.394	1.489	1.865			
(F) 31 July	PPO	8.710	9.026	4.696	8.692	6.018	7.428	1.952	2.445	0.348	0.117	0.8979
	POD	24.156	27.228	13.455	21.857	18.399	21.019	5.319	6.660			
(G) 14 Aug	PPO	2.890	8.895	9.311	8.574	4.007	6.735	3.038	3.804	0.302	0.070	0.9844
	POD	10.062	29.013	29.046	29.816	12.261	22.040	9.966	12.479			
(H) 28 Aug	PPO	4.842	1.460	2.056	2.673	11.707	4.547	4.201	5.261	0.288	-0.657	0.9362
	POD	25.042	4.875	9.055	11.948	39.394	18.063	14.108	17.666			

Figure 1. State-dependent regressions of POD and PPO activities in the vegetation period of beech trees.



Theory: State-dependent correlation of biochemical variables

The correlations between biochemical variables in a given physiological stage are regarded as state-dependent correlations. The conditions of existence of strong state-dependent correlation are the synchronized regulation of variables in the metabolism and the identity of their distributions. On the basis of these conditions, a theoretical equation has been derived from standardization of the variables of the distributions [1] (see equation 1). The slope of relationship of theoretical state-dependent correlation has been defined by the ratio of theoretical standard deviations of the variables. Its intercept depends from the standard deviations and expected values. State-dependent correlation of biochemical variables is very sensitive to the environmental condition [2]. The alterations occurring in the physiological state can be tracked with the serial of state-dependent regressions of biochemical variables [3].

$$x_1 = \frac{\sigma_1}{\sigma_2} x_2 + \frac{\sigma_2 \mu_1 - \sigma_1 \mu_2}{\sigma_2} \qquad (1)$$

y_i – i^{th} biochemical variables, μ_i – i^{th} expected value, σ_i – i^{th} theoretical standard deviation. The parameters of theoretical equation of state-dependent correlation can be estimated by regression analysis or from the means and empirical standard deviations of measured data.

Figure 2. State-dependent regressions of POD and PPO activities in the vegetation period of Penduncular oak.

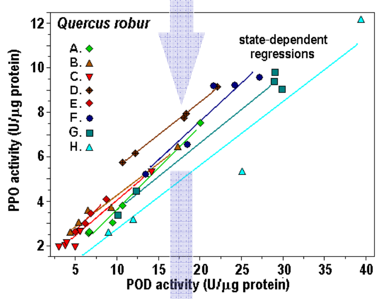
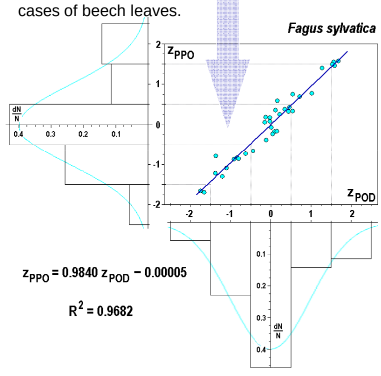


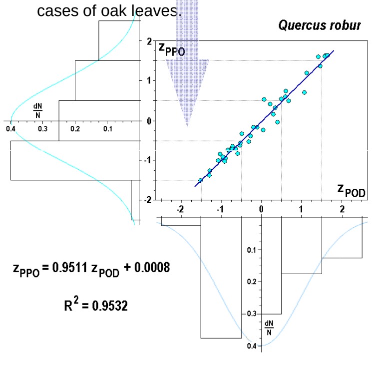
Figure 3. Empirical distributions and correlation of standardized POD and PPO activities in the cases of beech leaves.



$z_{PPO} = 0.9840\, z_{POD} - 0.00005$

$R^2 = 0.9682$

Figure 4. Empirical distributions and correlation of standardized POD and PPO activities in the cases of oak leaves.



$z_{PPO} = 0.9511\, z_{POD} + 0.0008$

$R^2 = 0.9532$

Table 3. Means and standard deviations at different environmental conditions (T – temperature (°C); P – air pressure (kPa); RH – relative humidity (%); GSR – global solar radiation ($MJm^{-2}day^{-1}$).

	Beech (*F. sylvatica*)				Penduncular oak (*Q. robur*)				Environmental condition			
Sampling	M_{PPO}	SD_{PPO}	M_{POD}	SD_{POD}	M_{PPO}	SD_{PPO}	M_{POD}	SD_{POD}	T	GSR	RH	P
A	4.416	2.091	7.170	3.639	3.403	2.088	10.727	5.508	18.0	7.96	57	101.13
B	2.739	0.930	6.245	2.692	3.367	1.502	8.598	5.191	14.0	12.30	55	101.10
C	0.875	0.179	0.857	0.198	2.300	1.451	6.011	4.605	35.0	15.88	37	100.15
D	3.102	0.875	7.243	2.147	6.860	1.401	16.292	4.733	17.8	9.74	56	100.44
E	1.804	0.114	3.864	0.328	2.68	0.593	6.394	1.489	23.3	27.69	59	101.50
F	2.988	1.662	8.835	5.858	7.428	1.952	21.019	5.319	17.3	18.00	62	101.82
G	2.827	0.397	7.966	1.371	6.735	3.031	22.04	9.966	20.2	12.30	70	101.41
H	1.510	0.239	4.355	1.050	4.547	4.201	18.063	14.108	18.1	17.53	69	101.69

Table 4. Correlation matrix of statistical and environmental parameters of the beech tree.
(*The data of the sampling at 15 May were omitted because of the weak fitting of the regression.)

Beech	ρ	Spearman's rho										
R*		M_{PPO}	SD_{PPO}	M_{POD}	SD_{POD}	m	b	R^2	T	GSR	RH	P
	M_{PPO}		**0.7143**	**0.8571**	**0.7857**	-0.0357	0.0357	0.0714	**-0.6071**	-0.4144	*0.2500*	0.1429
P	SD_{PPO}	**0.7292**		**0.8214**	**0.9643**	-0.0714	0.2143	**0.7143**	**-0.8929**	-0.3604	*0.0714*	0.2143
e	M_{POD}	**0.9509**	**0.7383**		**0.8571**	-0.3929	0.2500	0.3214	**-0.6429**	-0.2523	***0.5357***	0.4286
a	SD_{POD}	**0.6822**	**0.9792**	**0.7506**		-0.1786	0.3214	**0.6071**	**-0.9286**	-0.2523	*0.1786*	0.3571
r	m	-0.5978	-0.3028	-0.7159	-0.3899		**-0.5714**	-0.0714	0.1429	-0.3424	**-0.9286**	**-0.8214**
s	b	0.3827	0.1416	0.5013	0.2535	**-0.8290**		0.0714	-0.4286	-0.0901	0.4286	0.3214
o	R^2	0.1503	**0.7435**	0.2682	**0.7964**	-0.0829	0.1234		-0.6786	0.0360	-0.1429	0.2857
n	T	**-0.7711**	**-0.5569**	**-0.7902**	**-0.5672**	0.8775	-0.7076	-0.2625		0.2883	-0.0357	-0.2857
's	GSR	-0.4574	-0.3162	-0.3723	-0.2052	-0.0769	0.1695	-0.0888	0.2569		0.1982	0.6667
R	RH	*0.4699*	*0.1233*	***0.6520***	*0.2425*	**-0.9322**	0.7781	-0.0286	-0.7019	0.0455		**0.7143**
	P	0.2523	0.2335	0.4754	0.4019	**-0.8231**	0.8368	0.3109	-0.5641	0.4443	**0.8184**	

Table 5. Correlation matrix of statistical and environmental parameters of the oak tree.

Oak	ρ	Spearman's rho										
R		M_{PPO}	SD_{PPO}	M_{POD}	SD_{POD}	m	b	R^2	T	GSR	RH	P
	M_{PPO}		0.3571	**0.8810**	0.5000	-0.1667	-0.1429	-0.3810	*-0.5476*	-0.1317	**0.5476**	0.4524
P	SD_{PPO}	0.3133		**0.6667**	**0.9762**	-0.3095	**-0.8095**	-0.3810	*-0.1190*	-0.1796	**0.6190**	0.4286
e	M_{POD}	**0.9161**	**0.6481**		**0.7619**	-0.2143	-0.4524	-0.4524	*-0.3333*	-0.0838	**0.8095**	0.5714
a	SD_{POD}	0.2955	**0.9878**	**0.6196**		-0.3571	-0.7619	-0.4048	*-0.2381*	-0.2515	**0.6667**	0.4524
r	m	-0.2848	-0.4729	-0.3346	-0.5779		-0.2143	0.1429	0.4286	0.2755	0.0952	0.2381
s	b	0.2691	**-0.5291**	-0.0763	-0.4340	-0.3839		0.3810	-0.2143	-0.1198	-0.7143	**-0.6429**
o	R^2	-0.4429	-0.3724	-0.5335	-0.3123	-0.0206	0.3472		0.4762	-0.5509	-0.5476	**-0.8571**
n	T	*-0.4684*	*-0.2513*	*-0.4598*	*-0.2360*	0.1505	-0.0579	0.4025		0.2994	0.0714	-0.1429
's	GSR	-0.2695	-0.2439	-0.2405	-0.2309	0.4486	-0.2215	-0.2774	0.2967		0.2874	0.5988
R	RH	**0.5626**	**0.6096**	**0.7377**	**0.5875**	-0.0601	-0.3321	-0.4518	-0.6859	0.0610		**0.8095**
	P	0.2978	0.4164	0.4852	0.3555	0.2645	**-0.5853**	**-0.7329**	-0.5546	0.4000	**0.8182**	

(M_{PPO}, M_{POD} : the means of PPO and POD activities; SD_{PPO}, SD_{POD} : empirical standard deviations; m : slope; b : intercept; R^2 ; coefficient of determination; T : temperature; GSR : global solar radiation; RH : relative humidity; P : air pressure)

TÁMOP 4.2.1/B-09/1/KONV-2010-0006

References: [1]. Németh, Zs.I., Sárdi É., Stefanovits-Bányai É.: 2009. State dependent correlations of biochemical variables in plants. Journal of Chemometrics, **23** :197-210. [2]. Németh, Zs. I., Pozsgai-Harsányi, M., Stefanovits-Bányai, É., Sárdi, É.: 2009. Characterization of plant stress syndrome by some correlations of biochemical variables. Cereal Research Communications, **37**:141-144. [3]. Németh, Zs.I., Pozsgai-Harsányi M., Gálos, B., Albert L.: 2009. Stress sensitivity of correlation between POD and PPO activities in plants. Acta Silvatica et Lignaria Hungarica, **5**: 27-45.

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