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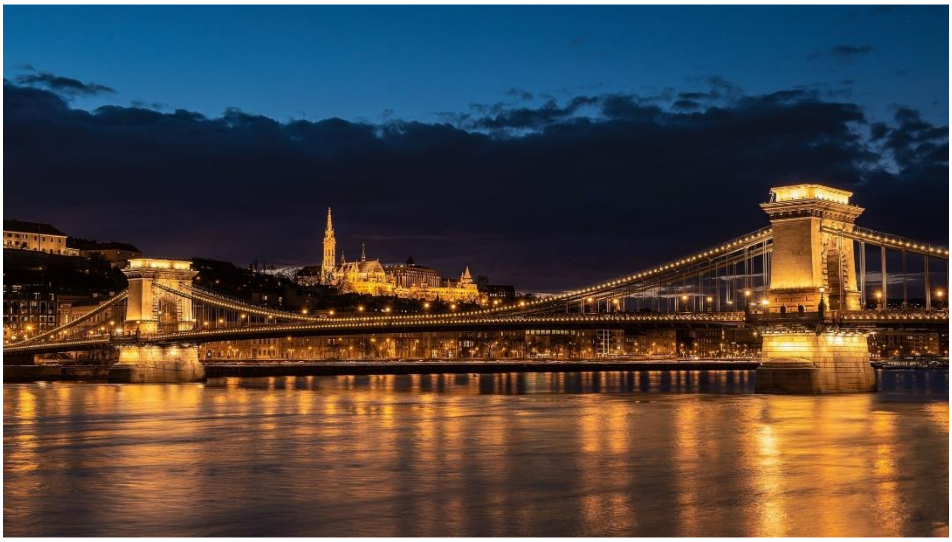

BOOK OF ABSTRACTS

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Development of genetic models to breed for mixed cropping systems

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1 Introduction

Mixed cropping, i.e. mixing different crops in the same field, provides agronomic advantages as increased productivity under low inputs conditions (e.g. for organic farming: Bedoussac et al. 2015) and higher yield stability (Raseduzzaman and Jensen 2017). In mixed cropping, choosing the right cultivars is critical for the performance of the mixture, as shown for pea-barley mixtures (Hauggaard-Nielsen and Jensen 2001) and maize-bean mixtures (Hoppe 2016). As performance in pure stand can strongly diverge from performance in mixture, estimating the ability of a cultivar to be mixed with another crop is therefore of utmost importance. For this purpose, concepts of General and Specific Combining Ability in hybrid breeding (Griffing 1956) have been adapted to cultivar and crop mixtures. Thus, these effects are called General Mixing Ability (GMA) and Specific Mixing Ability (SMA) (Federer 1993). In contrast to intraspecific mixtures, interspecific mixed cropping experiments often provide additional information, since harvested lots can be separated into their different grain fractions. Until now, statistical developments mobilizing the additional information provided by separated harvest lots to estimate mixing abilities in intercropping experiments have been neglected. The concept of Producer- and Associate-effects (abbreviated *Pr* and *As*, respectively) describes interactions between varieties sown in alternate row trials (Forst 2018). The producer effect *Pr* is the average performance of a cultivar grown in mixture with other crop-species, whereas the associate effect *As* is the average effect of a cultivar on the performance of the mixing partner. We used the fraction yields of a spring-pea (*Pisum sativum* L.) and spring-barley (*Hordeum vulgare* L.) mixed cropping experiment to determine *Pr* and *As* effects of different pea genotypes. The additional information provided by this approach is biologically more informative than GMA/SMA estimates, since it better reflects competition and facilitation occurring between different cultivars of the two crop-species.

2 Material and methods

Plant material comprised of 28 (plus 4 mixtures) and 7 (plus 1 mixture) morphologically diverse pea and barley cultivars, respectively, from European breeding programmes to compose bi-specific pea-barley mixtures. Fifty-six bi-specific pea-barley mixtures were arranged in an incomplete factorial design (Figure 1) and sown in 7.5 m^2 plots with two repetitions at two locations in Switzerland (Figure 2). Harvested grains were separated into pea and barley components. Variance components for both the GMA/SMA and the *Pr*/*As* model were estimated within a mixed model framework with best linear unbiased prediction. GMA of pea cultivars, SMA (interaction of pea cultivar with barley cultivar) and the error term were set as random variables with the assumptions for random effects of having a mean of 0 and being normally distributed. Similarly, *Pr* and *As* effects were estimated with the pea and barley component yields as dependent variables, respectively. Potential functional traits, such as early vigour of pea, were measured and evaluated using correlation analysis to relate them to GMA, *Pr* and *As* effects. When prerequisites for parametric test procedures were not fulfilled, non-parametric tests (e.g. Spearman rank-correlation) were applied.

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	peas	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32
barleys	No barley (pure stand pea) / No pea (pure stand barley)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B1	1	1				1					1				1					1			1				1			1			
B2	1	1					1			1						1		1					1						1		1		
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B4	1			1					1				1				1	1						1					1			1	
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B8	1			1					1				1			1				1					1			1		1			

Figure 1. Incomplete factorial design with 8 barley pure stands (7 cultivars and 1 mixture), 32 pea pure stands (28 cultivars and 4 mixtures), and 56 bi-specific mixtures of those.

Figure 2. Aerial image of one of the two trial locations.

3 Results

The proportion of GMA variance of pea, i.e. the variance in mixture yield explained by the presence of a given pea cultivar in mixture, was predominant over SMA variance, i.e. the variance due to interaction of pea and barley cultivars: GMA pea ≈ 50%, SMA ≈ 10%, residual ≈ 40%. There was a significant negative correlation between the pea *Pr* effects and it's *As* effects with Spearman's rho= -0.47. However, few individual genotypes were found with positive *Pr* and positive *As* effects. *As* effects of pea were correlated over locations (R^2=0.48). The GMA of pea was not significantly correlated with early vigour of pea (Spearman's rho=0.21), whereas *As* effects of pea were significantly negatively correlated with this trait (Spearman's rho= -0.36).

4 Discussion and conclusions

The GMA approach, based on the testcross methodology from hybrid breeding is a valuable tool to determine mixing ability in pea-barley mixtures. This potential is further pronounced by our finding that pea GMA variance is predominant over SMA variance, indicating the potential for breeding for mixed cropping. The GMA approach can be extended using the *Pr/As* concept for understanding trait influences on mixture behaviour. We observe a negative correlation between *Pr* and *As* effects, indicating a trade-off between a cultivar's performance and its companion-crop's performance as observed also by Forst, 2018, for wheat cultivar mixtures. However, our data suggests room for genetic improvement, e.g. by selecting deviating genotypes with both positive *Pr* and *As* effects. *As* effects were correlated over locations, indicating an underlying heritable component. Early vigour of pea was not correlated with GMA, however, it significantly negatively correlated with pea's *As* effect (its effect on the barley yield), indicating the surplus of precision and information on trait-performance relationships that the *Pr-As* concept gives compared to the GMA concept. The results allow to seize the effects of cultivar choice in the performance of crop mixtures and to propose breeding schemes and experimental designs for improving pea-barley mixtures.

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