A functional agrobiodiversity approach to improve organic wheat production

AMBROGIO COSTANZO[1], PAOLO BÀRBERI[1]

Key words: agrobiodiversity, composite cross population, cultivar, living mulch, organic farming, wheat

Abstract

Agrobiodiversity can improve organic and low-input wheat production, but a clear framework is necessary to translate scientific evidences into practice. Here we present results from a field experiment on common wheat, focusing on cultivar identity, genetic heterogeneity and on the inclusion of a legume living mulch. We conclude that selecting cultivar identities adapted to local macroclimate is crucial in enhancing yields, but this is not limited to modern pedigree cultivars. Old cultivars are, for example, better weed suppressors, and genetically diverse populations may better buffer climatic unpredictability. Living mulches do not always reduce wheat yield, but may reduce weed abundance

Introduction

Wheat is the leading crop for human nutrition in most temperate regions worldwide. Current yields are reported to be stagnating and dependent on external input supply (Brisson et al. 2010). In organic wheat growing, where environmental variation cannot be buffered through external inputs supply, changes in breeding and cropping systems design are necessary to ensure adequate and stable yields (Wolfe et al. 2008). The use of crop agrobiodiversity is thought to favour sustainable plant production (Newton et al. 2009) but there is an evident gap between scientific evidences and current agricultural practice (Ratnadass et al. 2012). This works aims at clarifying the impact of different categories of crop agrobiodiversity on wheat production and related agroecosystem services. These are (i) 'functional identity', i.e. the availability of adequate cultivars adapted to local environments and cropping systems, (ii) 'functional composition', i.e. the co-presence of complementary functional groups, and (iii) 'functional diversity', i.e. the use of genetically heterogeneous cultivars (Costanzo and Bàrberi, 2013).

Material and methods

As part of the SOLIBAM (Strategies for Organic and Low-input Integrated Breeding and Management) EU FP7 project, we compared common wheat (*Triticum aestivum* L.) cultivars and management systems representative of three categories of functional agrobiodiversity:

- Functional identity, represented by the identifying traits of cultivars with different geographic origin and breeding history;
- Functional composition, represented by the co-presence of wheat and a Subterranean clover (*Trifolium subterraneum* L. subsp. *brachycalycinum*) living mulch;
- Functional diversity, represented by the genetic heterogeneity of wheat crop population, increased by mixing cultivars or by sowing composite cross populations (CCPs), i.e. bulk progenies of half-diallel crosses between several parental genotypes, sown and re-sown season after season.

We carried out a field trial in 2010-11, 2011-12 and 2012-13 in the Centro Interdipartimentale di Ricerche Agro-Ambientali (CIRAA) of the University of Pisa (Italy). Experimental fields were part of a 5-year stockless rotation, with pigeon bean (*Vicia faba minor*) as preceding crop. Soil was an alkaline silty-loam at 5 m above sea level in the coastal plain of Tuscany (Italy), under a Mediterranean sub-humid climate with 900 mm average annual rainfall.

Wheat was sown either as a sole crop or with a subterranean clover living mulch. Living mulch was set up as an additive intercrop, by contemporarily sowing wheat and clover at the sole crop seed rates. Cultivars included a mixture of old Italian cultivars, an Italian pure line, a mixture of four Italian pure lines, a Hungarian pure line, two Hungarian and one British CCPs (Tab 1). CCPs were harvested and re-sown for the following season, upon an evolutionary breeding approach (Döring et al. 2011).

[1]Institute of Life Sciences, Scuola Superiore Sant'Anna, Piazza Martiri della Libertà 33, Pisa (IT), www.sssup.it, Email: a.costanzo@sssup.it, barberi@sssup.it

Tab 1. Experimental factors and treatments

Factor 1: Wheat cultivar		Factor 2: Cropping system	
Cultivar Group	Cultivar name and provenance	Wheat only	Living Mulch
Old Cultivars	Mix of old cvs (IT)	450 seeds m^{-2}	450 seeds m^{-2} (Wheat) + 800 seeds m^{-2} (Subterranean clover)
Commercial Cultivars	Bolero (IT)		
	Mix of modern cvs (IT)		
	Mv Emese (HU)		
Composite Cross Populations (CCPs)	Elite CCP (HU)		
	Hungarian CCP1 (HU)		
	Organic YQ CCP (UK)		

We monitored wheat phenology and wheat canopy height periodically during the crop cycle. We assessed weed density in vegetative stages, weed biomass in vegetative and reproductive stages, grain yield and yield components. Data were analysed by ANOVA, as a completely randomised design in year 1 and as a randomised complete block design in years 2 and 3. Wheat cultivars were compared through orthogonal linear contrasts.

Sowing was delayed to mid-February in year 1 due to excessive autumn rainfall, resulting in suboptimal establishment and in a very short growing season. In contrast, in year 2 sowing was done in mid-October and climate was favourable to wheat growing. In year 3, the trial was also sown in mid-October, but continuous rainfall throughout almost the entire crop cycle caused severe diseases outbreaks and lodging.

Results

Mean wheat grain yield reflected the extreme climatic variability of the three trial years, being 1.04 t ha^{-1} in year 1, 4.04 t ha^{-1} in year 2 and 1.46 t ha^{-1} in year 3.

For functional identity, three main distinctions between groups of cultivars were possible: (i) old cultivars grew significantly taller than any other cultivar, (ii) Italian cultivars had an erectophile growth habit and faster growth during tillering stage, while foreign cultivars had a prostrate growth habit and slower growth, (iii) Italian cultivars had an earlier growth cycle than foreign cultivars. Italian pedigree cultivars were the best yielding in all three years, while the mixture of old cultivars was the least yielding in year 2.

For functional composition, presence of the living mulch reduced wheat yield by 30% in year 1 ($p = 0.008$) but had no significant effects in years 2 and 3. It also reduced early season weed density in year 1 ($p = 0.021$) and 3 ($p < 0.001$), and weed biomass at wheat flowering in year 3 ($p = 0.011$).

For functional diversity, CCPs showed a higher heterogeneity in plant height and heading time, compared to both pure lines and cultivar mixtures. Furthermore, CCP growth cycle was slightly longer than that of the Hungarian pure line. As all the tested CCPs were foreign, they tended to yield less than the commercial pure lines. However, except in year 2, the same pattern was also observed for the Hungarian pure line, suggesting that no important disadvantages in yield could be attributed to crop functional diversity (Tab 2).

Tab 2. Wheat grain yield: deviation of cultivar groups average from field average in each growing season

	2011	2012	2013
Italian commercial	+ 14%	+ 8%	+ 50 %
Hungarian commercial	- 6 %	+ 13 %	- 22 %
CCPs	- 7%	- 6 %	- 26 %
Treatments compared: significance of orthogonal linear contrasts			
Commercial vs CCP	ns	**	**
Commercial Italian vs Hungarian	ns	ns	**

* significant at P<0.05; ** significant at P<0.01; *ns* not significant

Moreover, considering within-field variation in yield of each cultivar, CCPs showed a consistently lower coefficient of variation across years than modern commercial cultivars (Tab 3). These evidences suggest that, despite their expected low fitness to the Mediterranean climate, functional genetic diversity of CCPs may result in an enhanced buffer capacity against environmental variation.

Tab 3. Within-field coefficient of variation (%) for yield of cultivar groups in each growing season

	2011	2012	2013	Mean
Italian commercial cultivars	41.1	15.8	26.2	27.4
Hungarian commercial pure line	39.5	17.9	62.6	40.0
CCPs	33.4	14.1	18.9	22.0

Discussion

This work allows to unravel the potential of different agrobiodiversity use strategies to improve organic wheat production. Cultivar local adaptation emerges as the most important determinant of yield performance. However, broadening cultivar choice and system management options would be crucial in the perspective of reducing external inputs, optimising ecological processes and adapting cropping systems to climate change. Our main outcomes are that (a) modern commercial cultivars adapted to local conditions are the highest yielding, while old, tall local cultivars are the best weed-suppressive, (b) including a certain amount of genetic heterogeneity can buffer unpredictable environmental variation, (c) including a legume living mulch can help suppressing weeds. However, the strategies analysed in this work need to be optimised. The use of different cultivar types, e.g. modern vs. old, should be embedded into local agroecosystems and societal needs. Functional diversity strategies, as the use of heterogeneous populations, need further testing, and the creation and wider distribution of CCPs for different climatic regions. This would in turn require innovations in seed regulation, which currently forbids trade and exchange of heterogeneous seeds. Functional composition effects, like those addressed by intercrops and living mulches, need improved component choice and technical optimisation of the system through adequate sowing densities and management tactics. We are currently working on optimising wheat cultivar mixtures through a functional composition approach, to facilitate the choice of component cultivars based on the combination of key phenotypic traits.

Acknowledgements

This study was supported by the EU FP7 project SOLIBAM, grant n. KBBE-245058.

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