Breeding for specific bioregions: a genotype by environment study of horticultural and nutritional traits integrating breeder and farmer priorities for organic broccoli cultivar improvement

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Introduction

Organic agriculture now comprises 5% of overall agricultural production in the U.S. with an acreage growth rate of 15% in 2009. Consumer preference for more sustainably produced foods, combined with the perception that organically produced food is more nutritious, are the primary drivers behind the growth in demand. Broccoli is a significant crop for organic agriculture due to market demand as well as its nutritional contribution to the U.S. diet. The main broccoli production areas for conventional agriculture in the U.S. are in California, Oregon and Maine. However, organic broccoli production occurs across the country in diverse agro ecosystems and for diverse market segments. Organic growers need cultivars better adapted to organic and low external input growing conditions, but demands on specific characteristics can differ by crop. The commercial seed industry is challenged to satisfy the demands of organic agriculture, and often does not understand the special requirements of organic production systems that are characterized by diverse quality and adaptability criteria. Since organic farming is comprised of diverse types of organic growers, and since organic farmers have fewer tools at their disposal to influence their production environment to fit their crops, the assumption is that their seed cultivar needs and markets differ from their conventional production counterparts. Organic farmers want improved cultivars that display production stability under adverse environmental conditions, rather than cultivars that promise higher yields but largely lose that yield advantage because of inability to perform under conditions of organic production. An integrated study to understand organic growers' requirements and to evaluate performance of broccoli cultivars was conducted as part of the senior author's dissertation research. To define an organic broccoli cultivar ideotype, stakeholders' needs in the organic broccoli production chain were studied. In order to determine the adaptation of conventionally bred broccoli cultivars to organic systems, field trials were conducted to evaluate cultivars under conventionally and organically managed conditions in two main broccoli production regions in the U.S. Since broccoli is a relatively abundant source of phytochemicals, e.g. glucosinolates, tocopherols and carotenoids (Kurilich et al., 1999), that have been associated with human and plant health promotion, both horticultural traits (e.g. yield, head size and overall plant vigor) and nutritional composition have been evaluated. The results of horticultural trait and phytochemical content performance combined with farmer and breeder surveys and interviews will be used to generate strategies for the development of superior broccoli cultivars for the organic market.

Materials & Methods

The extent to which organic agriculture can utilize germplasm generated from conventional breeding programmes was explored through surveys, semi-structured interviews and field day participation with broccoli breeders (n=5) and conventional (n=18) and organic (n=38) farmers. Field days were held in two consecutive years in Oregon (2007-2008), at which organic and conventional growers were asked through field trial observation to identify the top 5 performing cultivars for their production system. Organic and conventional growers completed preliminary surveys identifying their priority broccoli traits and standard cultivars they used, while breeders ranked the primary trait objectives of their commercial breeding programmes. The horticultural and nutritional performance of 23 broccoli cultivars was compared between organic and conventional growing conditions through field trials with three replications conducted in the spring and fall between 2006 and 2008 in Oregon and Maine. Data was taken on thirteen different horticultural traits of value and phytochemical data on glucosinolates, carotenoids and tocopherols were evaluated from the broccoli samples derived from the field trials. The Oregon cultivar trial location was conducted at the same location that the farmer field days were held and the participatory data collected.

Results and Discussion

Grower and Breeder Surveys for Broccoli Trait and Cultivar Preferences

The surveys indicated that the size of the production acres and the market outlets of organic growers were more diversified, with a mix of fresh market and processed product growers, and conventional growers representing a higher percentage of processed product growers. Most of the conventional growers had an acreage ranging from 80 to 300 acres and aimed at mechanical harvesting. The acreage of organic growers ranged from 5 to 120 acres, and they tended to focus on fresh market production and seeked broccoli cultivars that provided a primary harvest and a continued harvest with side-shoot development. Results of the survey are summarized in Table 1.

Table 1: Grower and Breeder Broccoli Trait Ranking (1-5 scale)[1]

Broccoli Trait	Org Ranking	Conv Ranking	Breeder Priorities	Breeder Ranking for Org
Head Shape & Size[2]	1	2	*	*
Yield	1	2		
Disease Resistance[3]	2	3		*
Insect Resistance[4]	2	5		*
Abiotic Stress Resistance[5]	2	2		*
Stem & Head Color	3	2		
Weed Suppression	3	5		*
Uniformity in Maturing	3	1	*	
Bead Size	4	2	*	
Flavor	4	5		
Plant Uniformity	4	3	*	
Leaf Mass Coverage	5	4		
Nutrition[6]	5	5		
Mechanical Harvesting	5	1	*	
Placement of Crown	5	1		

[1] Ranking Scale (1-5): 1 as highest; * indicates top priorities for breeders
[2] Flat or domed: overall preference dome shaped
[3] black rot; club root; downy mildew; head rot; other diseases
[4] aphids; cabbage looper; symphylan; flea beetle; cabbage maggot
[5] heat tolerance; drought tolerance
[6] minerals; vitamins; phytochemicals (glucosinolates, carotenoids, tochopherols)

While both groups prioritized ‘head size, weight and overall yield’, conventional growers ranked ‘uniformity in maturing’ and ‘capacity to harvest mechanically’ higher than their organic counterparts. The grower survey results indicated that the organic grower prioritized ‘abiotic stress resistance’ and ‘disease resistance’ higher than their conventional counterparts. Factors more important to organic producers than to conventional growers included broccoli cultivars with vigorous growth in soils with potentially low or fluctuating mineralization rates of nutrients, or the ability to tolerate weed competition.

The breeder interviews indicated that the priorities for conventional breeding were traits such as ‘mechanical harvesting capacity’, ‘head shape and size’, ‘bead size’, ‘plant uniformity’ and ‘uniformity in maturing’. These breeding objectives outlined by the breeders directly aligned with the traits prioritized with the conventional growers. When the breeders were posed the question, how would these priorities change if they were breeding for an organic system, the breeders reprioritized the breeding objectives to ‘nutrient use efficiency’, ‘abiotic stress resistance’, ‘insect resistance’, ‘disease resistance’ and ‘weed competition’. These priorities aligned more closely with those priorities identified by the organic growers.

In the preliminary surveys both the organic and conventional growers identified ‘Arcadia’ as a standard cultivar that they use regularly. In addition to ‘Arcadia’ organic growers listed an assortment of cultivars used to support their production systems, whereas the conventional growers listed only one other cultivar (‘Emerald Pride’) suitable for broccoli production. When the organic and conventional growers selected their top 5 cultivars in the field trial, both chose ‘Arcadia’ and ‘Gypsy’, but the other three cultivars in the top 5 were not the same. Both the organic and conventional growers were ‘*surprised’* by the performance of select cultivars they hadn’t seen or considered previously including ‘Green Magic’, ‘Gypsy’ and ‘Maximo’ and discussed adopting various cultivars into their production systems in the future. In the post-field evaluation discussions, the organic growers expressed interest in knowing the cultivars with higher levels of nutritional traits with the intent that they could translate this information to their customer base and incorporate these cultivars into their production systems.

Genotype by Environment Interaction Field Studies:
Results of the genotype by environment field trials in Oregon in the fall of 2006 and 2007 demonstrated top performance for head weight, size and overall plant performance in the cultivars ‘Green Magic’ (680g/head; overall ranking 7.6 out of 9) and ‘Maximo’ (655g/head; overall ranking 6.2) and Gypsy (overall ranking 7.1). All three cultivars performed significantly better in the organic trials than the conventionally paired trial, which could be explained by the higher levels of available nitrogen in organically managed soils during the warmer fall months and the longer growing period. These cultivars are classified as mid-late maturing cultivars with estimated maturity days ranging from 78-88 days. ‘Arcadia’ was not a top performer in yield or head size in Oregon over the seasons; it ranked 5 on a scale of 1 (lowest) and 9 (highest) in overall varietal performance and had an average yield of 399g/head. The results were contrary to the grower cultivar selections that identified ‘Arcadia’ as the number 1 ranked cultivar. In the Maine fall trials of 2006 and 2007 all cultivars under organic conditions outperformed those grown under conventional conditions in head weight except one cultivar, ‘Everest’. Top ranking cultivars in the organic system for fall were ‘Packman’, ‘Green Goliath’ and ‘Belstar’ all cultivars categorized as early or mid-early cultivars with maturity days ranging from 55-70 days. Some varietal performance overlap occurs between Oregon and Maine organic and conventional in the fall trials, but the above mentioned cultivars distinctly outperformed all other cultivars. The open pollinated cultivar ‘Green Goliath’ demonstrated the most flexibility in overall performance for head weight, size and overall performance rating over all sites, all seasons and all treatments. The spring 2007 and 2008 field trials in both locations demonstrated few significant differences in cultivar performance under organic and conventional conditions. The best performing cultivars for spring trials in Oregon were ‘Green Goliath’ and ‘B1 10’, both early-to-mid-early season cultivars, while the best performing cultivars in Maine were ‘Fiesta’ and SBC 2519’ both mid-to-late season cultivars. Early season cultivars performed poorly in the spring trials in Maine producing very low overall yields (‘Early Green’, ‘OSU OP’, ‘Packman’).

Overall yield performance by season was distinctly different with average fall yields across both locations ranging from 250 to 780g/head compared to average spring yields of 80 to 450g/head. Greater number of degree days was observed in Oregon compared to Maine (1,790 compared to 1,600). In contrast, Oregon had fewer degree days in the spring compared to Maine (1,585 compared to 2,600). It is apparent that mid-to-late season cultivars are more productive in Oregon in the fall, while early-to-mid season cultivars are better adapted to spring environments. Conversely, for greatest productivity, Maine requires early-to-mid season cultivars for the fall and mid-to-late season cultivars for the spring. The best performing early-to-mid season and mid-to-late season cultivars for Oregon were not necessarily the best performers for Maine.

Genotype by Environment Interaction Glucosinolates:
The literature has demonstrated that concentrations of health-promoting nutrients in Brassicas depends on the cultivar, the season and the management system in which they are grown, including organic versus conventional conditions (Farnham et al., 2003; Charron et al., 2005; Meyer & Adams, 2008). Broccoli florets have been found to be particularly abundant in the glucosinolates glucoraphanin, glucobrassicin, and neoglucobrassicin. Glucosinolate concentrations in broccoli floret tissue have shown dramatic variation among different genotypes (Kushad et al., 1999). Evaluation of 10 broccoli genotypes over two years at the University of Illinois indicated that this variation in concentration for glucoraphanin was primarily due to genetic variation, while differences in neoglucobrassicin was due to environmental variation and genotype-by-environment interaction (Brown et al., 2002).

Glucoraphanin content in the broccoli cultivars derived from the field trials did not demonstrate season or location effect which is supported by the literature. However, genotypic variation was shown. The cultivars 'Arcadia', 'B1 10' and 'Gypsy' were the best performers consistently across locations, seasons and treatments. The glucobrassicin content showed a consistent year and season effect with higher levels in the fall compared to spring, and higher levels in fall 2006 compared to 2007. One aspect that characterized the season in 2006 was that the year was warmer and dryer. Best performing genotypes were 'Nutribud', 'USVL 093', 'USVL 048' and 'OSU OP'. For this trait, 'Arcadia' is in the bottom group. From the literature it is known that neoglucobrassicin is very responsive to biotic stress. Our data showed that there was a consistent treatment effect in which levels of neoglucobrassin from broccoli cultivars derived from organic trials on average outperformed those grown in conventional trials. Neoglucobrassicin content levels, in contrast to glucobrassicin, showed an overall higher level in spring than broccoli cultivars from the fall trials. Best performing genotypes were 'USVL 093', USVL 048', 'Beaumont', 'Gypsy' and 'Diplomat'. For this trait, 'Arcadia' was a mid performer.

Conclusions

The genotype by environment interaction study of broccoli, amongst others (e.g. Murphy et al., 2007 for wheat), demonstrates that traits of a cultivar are sometimes ranked differently when grown in an organic production system compared to a conventional system. This has strong implications for breeding strategies. The breeders interviewed acknowledged that more attention on abiotic and biotic stress resistance in a broccoli breeding programme is needed which is in accordance with the farmers' varietal requirements. The first findings of the field trials show that cultivar performance is influenced by season and region, and differences in treatment (organic versus conventional management). The field trials showed that there are cultivars with broad adaptation such as 'Green Goliath'. These cultivars performed across locations, seasons and treatments within the sub-top group, however, organic farmers would benefit more from cultivars specifically adapted to their region and season. The trial results showed a wide range of glucosinolate levels. Glucoraphanin was very genotype dependent, while glucobrassicin and neoglucobrassicin were more influenced by abiotic and biotic environmental factors. Therefore, there are opportunities for nutritional performance enhancement under organic conditions which would provide an added value to the product quality with respect to human and plant health. Further elaboration of the dataset will contribute to the design of regional breeding strategies for improved broccoli cultivars for the organic market.

References

Brown, A.F., Yousef, G.G., Jeffrey, E.H., Klein, B.P., Wallig, M.A., Kushad, M.M. & Juvik, J. (2002) *Glucosinolate profiles in broccoli: variation in levels and implications in breeding for cancer chemoprotection*. Journal of American Society Horticulture Science **127**(5): 807-813.

Charron, C.S., Saxton, A.M. & Sams, C.E. (2005) *Relationship of climate and genotype to seasonal variation in the glucosinolate – myrosinase system. I. Glucosinolate content in ten cultivars of Brassica oleracea grown in fall and spring seasons*. Journal of the Science of Food and Agriculture **85**: 671-681.

Farnham, M., Stephenson, K. & Fahey, J. (2003) *Glucoraphanin concentration of broccoli seed is highly influenced by genotype*. Hortscience **38**: 677.

Hale, A. L.., Farnham, M.W., Ndambe Nzaramba, M. & Kimbeng, C.A. (2007) *Heterosis for horticultural traits in broccoli*. Theoretical Applied Genetics **115**(3): 351-60.

Kushad, M.M., Brown, A.F., Kurilich, A.C., Juvik, J.A., Klein, B.P., Wallig, M.A. & Jeffery, E.H. (1999) *Variations of glucosinolates in vegetable crops of Brassica oleracea*. Journal of Agriculture and Food Chemistry **47**: 1541-1548.

Kurilich, A.C., Tsau, G.J., Brown, A., Howard, L., Klein, B.P., Jeffrey, E.H., Kushad, M., Wallig, M.A. & Juvik, J.A. (1999) *Carotene, tocopherol, and ascorbate contents in subspecies of Brassica oleracea*. Journal of Agriculture and Food Chemistry **47**: 1576-1581.

Meyer, M. & Adam, S.T. (2008) *Comparison of glucosinolate levels in commercial broccoli and red cabbage from conventional and ecological farming.* European Food Research Technology **226**: 1429-1437.

Murphy, K.M., Campbell, K.G., Lyon, S.R. & Jones, S.S. (2007) *Evidence of varietal adaptation to organic farming systems*. Field Crops Research **102:** 172-177.