Chapter 2
Crop Competitiveness

Abstract Organic agriculture is being practiced in many countries around the globe and the area under organic agriculture is gradually increasing. Many biotic and abiotic factors affect wheat production in the field; however, competition for water, light, space and nutrients is often severe under organic systems due to the existence of weeds in a larger number. Weed management in organic systems is more challenging because the organic system prohibits use of herbicides. Moreover, weeds are rapidly becoming resistant to herbicides. This has led the scientific community to use other management strategies such as breeding cultivars with improved competitive ability to cope with weed's infestation. Breeding for crop competitive ability requires selection of traits that confer competiveness against various stresses, which is becoming a main objective in breeding cultivars for organically managed systems. Competitive ability traits reduce weed germination, growth, establishment and seed set, ultimately leading towards an improvement in grain yield. This Chapter reviews the importance of crop competiveness and highlights various morphological traits that confer competitive ability in crop plants with respect to developing new wheat cultivars for organically managed lands with enhanced competiveness.

Keywords Competitive ability · Crop morphology · Interference · Intraspecific competition · Organic agriculture · Weeds · *Triticum aestivum*

Wheat (*Triticum aestivum* L.) covers the largest area (217 m ha) under any single crop in the world (FAOSTAT 2012). It thus contributes towards the use of large amounts of synthetic fertilizers and pesticides. Agriculture has made tremendous progress to feed the ever-increasing world population but at the same time we are facing serious problems and challenges. This is especially true in terms of overuse and inappropriate use of agro-chemicals to make the soil fertile and to control weeds and diseases. This has resulted in contamination of water, loss of genetic variability, and deterioration of soil quality ultimately affecting the global ecosystem. Sustainable agriculture in the form of organic farming/agriculture has emerged as a new concept to address these challenges. Organic agriculture can be defined as a *production system that aims to promote and enhance agro-ecosystem health while*

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discouraging the use of off-farm inputs (Reid et al. 2009). Basically, organic agriculture focuses on improving soil fertility and reducing the use of external inputs by avoiding chemical/synthetic fertilizers, insecticides/pesticides, pharmaceuticals, and genetically modified organisms (GMO). The Codex Alimentarius Commission, an international food standard organization established in 1963 by the Food and Agriculture Organization (FAO) of the United Nations (UN) and the World Health Organization (WHO) defines organic agriculture in detail: *Organic agriculture is a holistic production management system which promotes and enhances agro-eco-system health including biodiversity, biological cycles and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using where possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system* (Sligh and Christman 2003).

Organic agriculture is being practiced in many countries around the globe and the area under organic agriculture is expanding yearly. In 2011, organic agriculture was practiced on more than 37.2 m ha worldwide with 1.8 million producers and the global market reaches US$62.8 billion (Willer and Kilcher 2012). The total organic land constitutes 0.86 % of the total agricultural land (Willer and Kilcher 2012). The Australian/Oceania continent accounted for 12.2 m ha followed by Europe (10.6), Latin America (6.8), Asia (3.7), North America (2.8), and Africa (1.1) and shared 33, 29, 18, 10, 7, and 3 % of the total land area under organic production, respectively (Willer and Kilcher 2012). The demand for organic products is mainly present in Europe and North America where it generates 97 % of the total global revenues (Willer and Kilcher 2012). The North American demand is increasing at a rapid pace and will eventually overtake Europe to become the world's largest market (Reid et al. 2009).

2.1 Importance of Crop Competitiveness

The availability and use of chemical fertilizers, pesticides, and herbicides after the Green Revolution has resulted in a tremendous increase in grain yield of various crops, including wheat. Farmers have successfully grown crops in weed-free environments over the last five decades through the widespread use of herbicides. Many types of weeds infest wheat crop (Fig. 2.1) and large variability in losses due to weeds have also been reported, such as 31–41 % in rice (*Oryza Sativa*) (Bhatt and Tewari 2006), 16–29 % in barley (*Hordeum vulgare*) (Didon and Bostrom 2003), up to 40 % in peas (*Pisum sativum*), 40 % in canola (*Brassica* sp.) (Harker 2001), 77 % in sugar beet (*Beta vulgaris*), and 100 % in onions (*Allium cepa*) (Vanheemst 1985). Mason and Spaner (2006) reported a yield reduction of 40 % in trials conducted on organically managed land in Canadian environment using 32 spring bread wheat (*Triticum aestivum* L.) cultivars. The estimated crop losses in Canada due to weeds are $984 million in 58 different commodities, with a

Fig. 2.1 Reported weed species (their common names) in Canada (*yellow*) and other parts (*green*) of the world that infest wheat field

share of $372 and $612 million of eastern and western Canada, respectively (Swanton et al. 1993). It has been reported that 1–3 Canada thistle plants/m^2 can reduce wheat yield by 12 % whereas a reduction of 36 % has been reported with 13–20 thistle plants/m^2 (Infanger 1956). Similarly, weed competition from *Avena sterilis* L. resulted in 23 and 19 % lower straw and grain yield in wheat, respectively. Gonzaliz-Ponce and Santin (2001) suggested that *A. sterilis* competes with wheat plants due to its emergence at the same time and great demand for nutrients and water. In another study, *A. fatua* and *Phalaris minor* were termed as "troublesome grassy" weeds that had shown a 30 % grain yield reduction in wheat. In addition to grain yield reduction, weed infestation also affects tillering ability, number of spikelets/spike, and quality (Khan et al. 2012). The bulblets of wild garlic and onion in wheat fields considerably influenced bread texture, color, and flavor and thus spoil flour quality (Qasem 2003). Moreover, increased herbicide resistances in weeds (Powles et al. 1997) have resulted in grain yield reductions in various crops, especially in cereals. This has directed scientists/researchers to take into account the importance of crop competiveness for weed management in the field. Semi-dwarf wheat cultivars, having height reducing genes (*Rht*) in the background, developed as a result of Green Revolution, are input responsive and high yielding but may be less competitive against weeds than older wheat cultivars developed before the Green Revolution (Mason and Spaner 2006).

The rate of weeds becoming resistant to herbicides is increasing at a very rapid pace due to continuous use of herbicides on a yearly basis (McDonald and Gill 2009). Deirdre and Donald (2001) reported various cases of herbicides resistance in 20 different wheat growing countries around the world. *Lolium rigidum*, *Avena* spp., *Raphanus raphanistrum*, along with some other weed species have shown most significant resistance against various groups of herbicides in Australia (Preston et al. 1999). This resistance of weeds to herbicides has forced farmers to use integrated weed management strategies (IWMS) to cope with this problem. The IWMS mainly rely on crop competitive ability that minimizes the herbicide cost/reliance and reduces environmental contamination. Breeding for crop competitive ability is basically the selection of those traits that confer competiveness against various stresses. This may become a main breeding objective: to breed cultivars for organically competitive management system by reducing weed germination, growth, establishment, and seed set, ultimately leading toward an improvement in grain yield.

2.2 What is Crop Plant Competition?

Crop plant competition (Fig. 2.2) is the demand for a common pool of resources (water, light, space, and nutrients) that is often limited in field conditions and is a major determinant of crop yield, especially in case of cereals. Competition can be of two types; intraspecific (between plants of the same species) and interspecific (between plants of different species). In organic farming, the interspecific competition is severer than conventional management systems due to the existence of more weeds. Christensen (1993) argued that interaction between plants is "interference" that can be positive, negative, or neutral. In organic environments, negative interference always exists between crop plants and weeds and is referred to as competition. Various studies have been conducted to find out the relative competitiveness of various crops against weeds (Holman et al. 2004; Lutman et al. 1994; Pavlychenko and Harrington 1934). The competitive ability of these crop species in order of their competitiveness is shown in Fig. 2.3. Weed–crop competition or competitive ability of a crop can be estimated in two ways, i.e., the suppression of weed growth by crop plants or grain yield reduction of crop plants by weeds. This dominant–recessive relationship of crop and weed plants, or vice versa, depends on genetic, management, and environmental factors. Challaiah et al. (1986) and Lemerle et al. (1996a) emphasized that crop tolerance and weed suppression are two separate characteristics, not necessarily present in the same genotype but both are highly correlated to each other (especially in wheat). The ideal genotype should have these two traits and therefore can perform equally in organic and conventional management systems by tolerating as well as suppressing weeds. Weed–crop competition can be divided into three basic categories; (1) weed-related factors including weed species, weed density, weed emergence time, duration of weed presence in the field, (2) crop-related factors including genetic response, crop species, crop cultivars, canopy cover, plant height, light interception rate, leaf width and angle, and (3) management-related factors including seeding rate, time, and density, time of irrigation and fertilization, soil and other environmental conditions, and efficiency of weed control methods. The most important factors of competitiveness are discussed in detail.

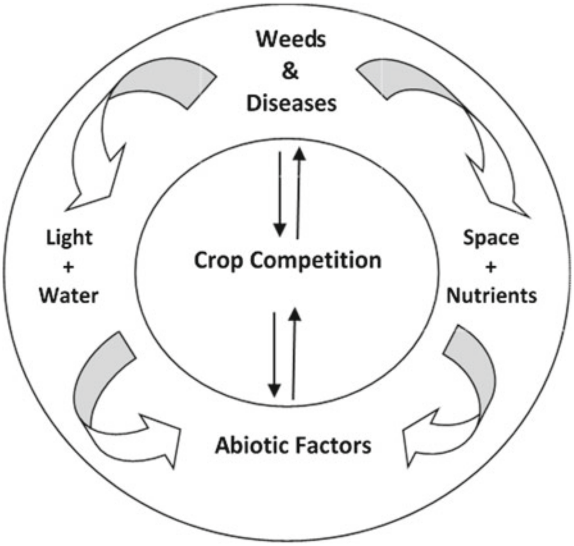

Fig. 2.2 Schematic diagram of crop competition with biotic (weeds and diseases) and abiotic factors

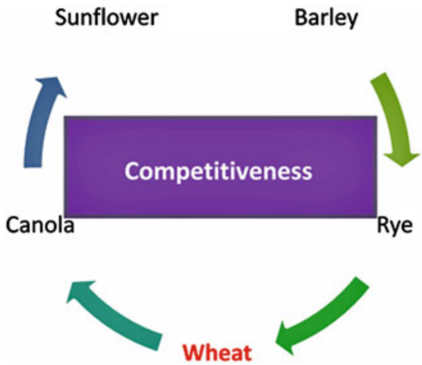

Fig. 2.3 Order of competitiveness in various crops against weeds

2.3 Association of Plant Traits to Competitiveness

Various plant traits affect competitive ability and vice versa. The negative effects of plant competition include shortage of water, nutrients and light, susceptibility to diseases and lodging, biomass/yield reduction, etc. Salisbury (1936) wrote that *competition is severe in the plant world, no one can deny and this is operative in all phases of development.* Therefore, it is difficult to find a crop plant in field conditions that have not been affected by its neighboring community, either of the same or different species. The existence of competition in the field makes it difficult to determine plant traits that are contributing to plant competitive ability because they are not only affected by the management practices (such as seeding rate, plant spacing, sowing depth) but also due to the environment and genotype x environment x management interactions. Moreover, competition is a population phenomenon and not simply the interaction with a single crop plant. Several authors advocate the use of morphological, physiological, biochemical, or behavioral characteristics to measure competitive ability (Lemerle et al. 2001a, b). However, any trait can confer competitiveness if it has the ability to rapidly utilize available resources and can increase its above-ground biomass as compared to its neighboring plants with which it competes (Donald 1968). Crop competitiveness is a genetic trait that is influenced by genotype, management, environment (their interactions), and is dependent on traits like plant height, early season vigor, light interception, leaf area index (LAI) and architecture, tillering ability, canopy structure, crop ground cover, earliness, nutrient use efficiency, lodging, and disease resistance. Mason and Spaner (2006) suggested that plant characteristics that exhibit a high degree of crop competitiveness against weeds are highly desirable in organically managed lands. Moreover, identification of new traits that confer competitiveness against weeds is a perquisite to breed/develop new cultivars for organic agriculture. Crop competitiveness cannot be attributed to a single plant trait; rather it is a sum of interaction of several plant characteristics. Early season vigor is directly linked with the competitive ability of the crop (Bertholdsson 2005) and later in the crop growing season, it confers competition against weeds (Huel and Hucl 1996). Plant traits that exhibit a positive correlation with early season vigor include rapid early growth rate (Froud-Williams 1999), LAI (Huel and Hucl 1996; Lemerle et al. 1996a, b) and tillering ability (Lemerle et al. 2001a), but it is also influenced by management practices like seed rate/plant density, seeding depth, and row spacing.

The relative emergence time of crop plants strongly influences competitive ability in cereals. If emergence of crop plants occurs before weeds, they will be able to use much of the limited resources as compared to weed plants which will ultimately give rise to a competitive advantage. Relative emergence time was studied between barley and *Sonchus arvensis* (sow thistle), where the authors reported that emergence of crop plants 4 days before weeds resulted in 90 % of the above-ground crop biomass. An opposite scenario occurred when crop plants emerged 8 and 26 days after weed plants and this late emergence resulted in a decreased above-ground crop biomass coverage by 50 and 10 %, respectively (Eckersten et al. 2008, 2010).

Early season vigor is one of the most important traits contributing to crop competitiveness. A plant that efficiently utilizes resources during early life cycle/ growth stages in terms of greater photosynthetic active radiation (PAR), accumulation of biomass, and tillering improves competitive ability. Early season vigor can be easily determined on the basis of early seedling size (width and length of seedling leaves), germination percentage (Lemerle et al. 2001a, b), and early plant biomass (Zerner et al. 2008). In a durum wheat experiment, cultivars possessing high early biomass accumulation and greater PAR were found best competitors against weeds (Lemerle et al. 1996b). This study also reported a strong negative correlation between first leaf length and width, and seedling biomass accumulation with grain yield loss and weed dry matter. Similar results have been reported in barley, oats, and wheat, where early season vigor was found to be strongly correlated with first leaf length and width (Lopez et al. 1996). Early season vigor is highly dependent on relative growth rate (increase in plant biomass per unit of time) of a crop. High relative growth rate in early growth staged confers better competitive ability (Grime 1979).

Plant height also has a pronounced effect on grain yield and is one of the most extensively reported and desired traits with respect to crop competitiveness. Mason et al. (2007), Cousens et al. (2003a, b) and Gooding et al. (1993) reported that plant height is directly linked to plant competitiveness. This relationship was supported previously by Cudney et al. (1991) who mentioned that taller cultivars are more competitive than shorter ones because of better light interception, and a direct association with photosynthetic activity of the plant in general. The importance of *Rht* genes in wheat was evaluated with respect to short-statured plants in an organic environment where the authors reported high weed (*Alopecurus myosuroides*) infestation and linked it to a reduction in shading ability of short-statured wheat plants (Gooding et al. 1997). This reduced shading ability caused increased penetration of photosynthetically active radiation through the wheat canopy. Wheat was reported to be the weakest competitor among cereals (Lemerle et al. 1995). With the introduction of semi-dwarf wheat cultivars during the Green Revolution, *Rht* (height reducing) genes are being incorporated and these cultivars are not performing well in organically managed systems due to less suppression of weeds, particularly as a result of their reduced plant height.

Thus, breeding for enhancing grain yield in wheat has decreased competitive ability to a considerable degree that has resulted in reducing early leaf area development (Rebetzke and Richards 1999) which has been considered as one of the main traits contributing toward competitive ability (Coleman et al. 2001). Similar findings have also been reported by Watson et al. (2006) in an experimental study involving 29 barley cultivars under Canadian environment where authors reported that if cultivars do not exhibit enough plant height with respect to their competitors, they must have enhanced and elevated leaves well above the ground and covered more surface area to maximize their light interception. Tall wheat cultivars were found to be capable of using more PAR and solar radiation in the range of 400–700 nm, and thus helped wheat suppress weeds (Champion et al. 1998). Tall rice cultivars also possess greater competitiveness and it was observed that plant height at very early stage of plant development can be a good indicator of competitive ability and to screen lines in standard nurseries (Caton et al. 2003; Moukoumbi et al. 2011). Plant height was found to have positive and significant correlation with competitive ability of crops; and the shortest cultivars when grown in a weedy competitive environment resulted in greater yield reductions and increased weed biomass (Huel and Hucl 1996).

Weed population is directly dependent on plant height of crop plants and weed species. It is also a major determinant of crop competitive ability because competitiveness of a given crop varies between different weed species. In an experiment on wheat competitive ability using near-isogenic lines, plant height showed a linear relationship to decrease weed seed production (Seefeldt et al. 1999). A similar trend of plant height in 20 winter wheat cultivars was reported by Wicks et al. (1986) who mentioned that cultivars taller than 83 cm reduced weed growth to a greater extent by capturing more light than shorter cultivars. In a similar study, Yenish and Young (2004) reported that tall (~130 cm) wheat cultivars decreased goat grass (*Aegilops cylindrica*) by 45 % as compared to short-statured (~100 cm) cultivars However, two shorter cultivars were also termed the best competitors with weeds suggesting that there are traits conferring competitive ability other than plant height (Wicks et al. 1986).

Crop canopy development, LAI and leaf shape/structure, angle, and number are other traits that are linked to competitiveness. It has been reported that semi-dwarf cultivars of wheat have smaller cells than older/conventional cultivars and this shorter cell size contributes to reduced leaf area and shorter coleoptiles length (Vandeleur and Gill 2004). The opposite or no differences were reported in another study conducted by Entz et al. (1992) suggesting that these undesirable traits can be improved by breeding (Ellis et al. 2004). Jennings and Aquino (1968) suggested that elevated competitive ability of rice was directly linked with high LAI. Strongly competitive plants have strong and spreading leaves. In an interesting study conducted on two wheat cultivars (Spark and Avalon), Seavers and Wright (1999) found Avalon to be a strong competitor due to the presence of re-curved leaves and more rapid canopy development than the more upright growing Spark. Gaudet and Keddy (1988) determined crop competitive ability and reported a linear relationship between easily observable characteristics and competitiveness ($r = 0.74$), where plant biomass explained 63 % of the total variation. Other characteristics, including leaf shape, height, canopy area, and diameter explained residual variation. Leaf area index was negatively correlated with weed seed yield and had no impact on grain yield reduction in wheat (Huel and Hucl 1996). In later growth stages, flag leaf characteristics like length, width, and angle also played a key role in suppressing weeds and maintaining a healthy crop stand. A strong negative correlation between flag leaf length and grain yield reduction was reported in the same study. However, care must be taken if breeding is done for dryland or drought prone areas because a high LAI can have a negative impact on grain yield (Richards 1983) under water limited conditions. Richardson et al. (2001) proposed that breeding for organic agriculture is more practicable if screening for candidate lines is done on the basis of visual observation for plant growth habit, leaf habit, leaf angle, leaf inclination, and visual scoring or image analysis of canopy coverage, than from light interception or a quantification of weed biomass per unit area.

Light interception is another important trait linked with weed suppression or with a resistance to yield suppression by weeds. It has been well documented that cultivars of winter wheat and spring cereals vary considerably more for shoot competitive ability than root competition, suggesting the importance of light interception in crop competition (Lucas and Froud 1994; Satorre and Snaydon 1992). Shoot morphological traits, including long main shoot during tillering, small leaf angle, and less time of emergence are important traits directly associated with competition for light (Didon 2002). Moreover, wheat cultivars with more ground cover exhibit high light interception. Ground cover is directly affected by leaf inclination, plant height, and row spacing. Later developing or smaller weeds are more susceptible to light competition and, therefore, it was recommended that selection for taller planophile wheat cultivars with narrow row spacing (12–17 cm) may provide an effective strategy to control losses due to weeds as compared to erectophile genotypes (Drews et al. 2004).

Overall, canopy development of a specific crop is highly dependent on its light interception rate, especially during the early stages of its life cycle. Fischer et al. (2001) described the direct association of light interception with crop competitive ability due to a negative correlation of LAI and PAR with weed biomass in rice. Greater leaf area and weight were present in the most competitive rice cultivar (Johnson et al. 1998) and these two traits reduced the amount of photosynthesis that is required to produce a given leaf area for light interception (Dingkuhn et al. 1999). Light interception varied considerably from one genotype to another and was also highly dependent on management practices like row spacing, fertilizer application, and number of irrigations during crop growing season. Light interception increases continuously until 90 days after sowing in wheat and then decreases slowly until maturity (Mishra et al. 2009). These results suggest that selection for light interception during early growth stages could improve competitiveness by increasing PAR interception and radiation use efficiency (RUE) (Zhou et al. 2011).

High tillering ability in cereals is also a desirable trait to obtain maximum grain yield per unit area and has been reportedly linked to above-ground canopy coverage and shading ability (Didon and Hansson 2002; Korres and Froud-Williams 2002). In an experiment to study the differences of competitive ability between old and new wheat cultivars, Fang et al. (2011) reported superior competitiveness of an old wheat cultivar/land race (Pinglang 40) over a modern cultivar (Changwu 135) due to greater tillering capacity, taller plants, larger root system, and LAI of the Pinglang 40.

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