The Role of Harvest Index in Improving Crop Productivity: A Review

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Abstract
Harvest index (HI) is a measure of success in partitioning assimilated photosynthate. An improvement of crop harvest index means an increase in the economic portion of the crops in certain level. HI is a novel trait which contributed significant role in improvement of crop productivity which could solve the problem of food supplies for the rapidly increasing population. The objective of this paper was to review the role and progress of HI in improving crop productivity. Although crop HI influenced by both environmental and genetic factors, the progress improvement of HI and yield through crop management technique and breeding method strategy is an anticipative. In addition, the knowledge of genetic mode of expression of HI provides information for breeder to determine next breeding method.
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Introduction
The production of yield in cropping systems is a consequence of many biological processes resulting in biomass and/or seed production. Economic yield and biological yield (biomass) are terms used to describe dry matter partitioning in plants. Harvest index(HI) is the ratio of grain yield to total biomass (Donald and Hamblin 1976; Hay, 1995 and Sinclair, 1998) is a trait that is the cumulative result of allocation of acquired resources and used in efforts to improve yields in seed producing crops (Reynolds and Langridge, 2016). HI is one of the factor that contributing in improvement of any crop to a certain extent (Reddy *et al*., 2003). It describes plant capacity to allocate biomass (assimilates) into the formed reproductive Parts and important trait in plant breeding (Wnuk *et al*., 2014). Also, the harvest index can be defined as been the physiological efficiency and ability of a crop for converting the total dry matter into economic yield (Sharifi *et al*., 2009).

In several crops, such as wheat or other cereals, the considerable progress in breeding for higher yields is achieved mainly through man-made selection forces for the harvest index (Gutam, 2011; Mazid *et al*., 2013). According to Yang and Zhang (2010) the proper crop management holds great promise to enhance harvest index, and consequently, achieve the dual goal of increasing grain production and saving water.

Some researchers indicate that the dramatic increase in the grain yield of major world cereal crops is due mainly to increases in harvest index and to a lesser extent the biological yield. In cereals it is generally accepted that the major contribution of plant breeding to improved yields has been through increased HI (Wilson, 1987). In maize, for example, harvest index changed from 24% in 1950 to 43% in 1970, increasing yield from 3 tons/ha to 8 tons/ha (Acquaah, 2009).

Despite this, currently, food production for a rapidly growing population and climate change is the major challenge. Improving yield of grain crops is needed to ensure food supply for the rapidly increasing population. However, without improving harvest index, increase in yield could not be achieved. In view of this, harvest index play significant role in improving crop productivity, and the objective of this paper was to review on the role and progress of harvest index in crop productivity.

Discussion
Importance of harvest index (HI)
Yield, in the eyes of breeders, is considered to have two main components: biomass, the ability to produce and maintain an adequate quantity of vegetative material, and *partition*, the capacity to divert biomass to the desired harvestable product (seeds, fruits, or tubers etc.). Therefore, the partitioning of assimilate is very important in obtaining maximum yielding ability. Partition, in general, takes the form of enhancement of yield of desired parts of the plant product at the expense of unwanted plant parts (referred to as increasing the harvest index) (Jack *et al*., 2014).

Yield of a crop is the function of biomass x harvest Index. Different authors indicated, yield improvement associated with increasing harvest Index (Sharma-Natu and Ghildiyal, 2005). Low crop harvest index is the major cause of less crop yield and vice versa. Ambrose and Hedley (1984) reported that 95 % of the plants in a high yielding pea crop had harvest index (HI) values of 40 to 70%. The HI may increase or decrease if seed yield changes more, or less, rapidly than total dry matter (TDM).

Harvest index could be used as selection criteria for breeder to improve yielding ability of a given crop. It is

useful in describing yield differences between lines. It is an appropriate trait to target for increasing yield potentials for crop breeding activities (Sadras and Richards, 2014). The highest seed yields are often associated with high HIs which then become an important selection criterion in plant breeding (Pilbeam, 1996). A more comprehensive understanding of harvest index and the basis upon which variations in harvest index are achieved among different genotypes would be of considerable advantage to food production systems. Genotypes expressed higher HI can be considered as ideal materials for selection in order to improve yield productivity, and therefore, harvest index could be included as the objective of plant breeder. Different authors reported high yielding varieties generally gave higher HI than lower yielding varieties among sweet potato landraces (Kays, 1985; Nwankwo *et al*., 2018).

Factors Cause variation of harvest index (HI)
Between crop species
Harvest index which measure the degree to which crop partitions photo assimilate into grain varied among crop species. This may due to the difference in growth habit, difference growth stage, the ripening period or fruit setting varied among crops. Harvest index (HI) of root and tuber crops greater than HI of grain crops and the HI of water-melon *(Citrullus vulgaris)* is ≥ 0.9 (Ismail, 1993). In cereals, HI values between 0.3 and 0.6 dominate (Hay, 1995). Harvest index also varied among different cultivar or lines of similar crop species. Abdalla *et al*. (2015) reported variations in harvest index among lines of fababean irrespective of environments, line *C.86* had higher harvest index (32.4, 43.4 and 35.8) in the three seasons, respectively. However, *Triple White* line had the lowest mean harvest index (21.2%, 37.3% and 25.7%) in the three seasons respectively.

Most cereal crop cultivars are determinate, flowering within a very small skylight of time and then entering a grain-filling period such that vegetative and reproductive growth is separated in time. Determinate crops generally have higher harvest indices as most crop resources are diverted to grain production once flowering has commenced. Harvest index more variable in indeterminate than determinate crops (Unkovich *et al*., 2010).

Environmental variation
Climate change influenced crop growth parameter leaf a Leaf area index (LAI), aboveground dry matter (ADM), and harvest index (HI). Change of climatic parameters such as increasing of temperature and precipitation decreased the grain production which resulted in lower values of HI (Banu *et al*., 2017).

Effect of temperature on harvest index (HI): For most plants reproductive development is sensitive to a wide range of environmental impacts, with many grain crops having a preferred temperature range for flower and seed development. Large variations in temperature outside of this range may cause problems with flower or seed growth. Temperature stresses on reproductive performance of crops also affect HI. Seed or flower development is constrained due to specific effects on reproductive apparatus; harvest index is likely to be significantly reduced, especially for determinate crops. The simplest example of a temperature extreme is frost, with freezing injury causing flower or seed abortion (Unkovich *et al*., 2010).

Heat and drought: Heat and drought have multiple, negative impacts on crop yields, including reducing leaf photosynthesis and enhancing leaf senescence rates. More critically for yield determination, however, are the reported effects of decreasing grain number when heat stress occurs before or around anthesis and reduced grain weight when it occurs during grain filling (Dolferus *et al.,* 2011; Ugarte *et al*., 2007). While drought represents a process that develops and intensifies slowly, heat stress can occur very abruptly and even short episodes of high temperature can cause a severe decline in grain yields. Short occurrence of heat stress can reduce crop yield considerably causing low resource use efficiency (Siebert *et al*., 2014). These results are an important indicator that factors contributed to crop yield losses are directly cause lower values of harvest index.

Crop growth season: Highest harvest index was recorded under favourable environmental condition than unfavourable condition over three growing season of fababean (Abdalla *et al*., 2015). Similarly, Harvest index registered higher values under more favourable soil and climatic conditions than under less favourable conditions in different maize growing areas (Ion *et al*., 2015).

Mohamad *et al*. (1994) reported harvest index was higher in main season (40.2%) than off-season (35.2%) among rice varieties. The harvest index among 20 released rice varieties was ranged from 0.29-0.42 and 0.31-0.51 in offseason and main season, respectively.

Harvest index tended to correlate negatively to plant height when the climatic conditions were less favourable for growing maize and tended to correlate positively up to a certain level when the climatic conditions were more favourable, especially when these were associated with favourable soil conditions (Ion *et al.,* 2015).

Table 1: Harvest index of different crop species

Crop species	Yield(kg/ha)	HI	References
11 variety of haricot bean	678.2 - 2709.3	0.28 – 5.0	Tadesse *et al*.,2014
3 variety of haricot bean	2246-2376	0.5-0.55	Girma *et al*.,2014
3 varieties of common bean	13247-14932	0.28-0.35	Melaku .,2012
6 faba bean line	2546 -5353	0.21- 0.43	Abdalla *et al*., 2015
6 potato variety	7530-14240	0.7-0.8	Mazurczyk *et al*.,2009
10 varieties of sweet potato	8090 -17390	0.35-0.53	Nwankwo, *et al*., 2018
maize	-	0.2-0.56	Ion *et al*.,2015
10 winter wheat varieties	5800 -7760	0.48-0.56	White and Wilson,2006
26 spring wheat genotypes	6000-7500	0.45-0.51	Foulkes *et al*.,2015
20 released varieties of rice	556-996gm/20plants	0.31-0.51	Mohamad *et al*.,1994

Crop management

Different level of crop management influence harvest index ultimately improves crop productivity. Bekele *et al.* (2016) reported highest harvest index (35.3%) recorded from intercropped maize and soybean than sole cropped maize (31.7%). Getachew(2007) also reported that higher harvest index was from intercropped maize with potato than sole cropped maize. In contrary to this, Gutu *et al.*(2015) reported sole maize cropping system gave higher harvest index (0.39) than intercropped maize and soybean (0.37).

Plant population: Different authors reported highest HIs obtained at high plant population densities. According to Ion *et al.* (2015) the highest average values of the harvest index were registered at plant density of 70.000 plants ha-1 in maize. Kerby *et al.* (1990) pointed out that high plant density in cotton resulted more dry matter leaves and stems relative to fruit and thereafter low harvest index (HI). The higher number of HI (38.11%) was obtained from 25% (83, 333 plants /ha) soybean population than 50% and 75% soy bean populations (Gutu *et al*., 2015).

Nutrients: Application of potassium (K) at the highest rate (90 kg ha^{-1}) increased Harvest index (0.39) due higher K level was attributed to the more dry matter partitioning into the reproductive parts (ears) of maize (Amanullah *et al*.,2015). Ayaz (2001) reported nitrogen increased total dry matter (TDM) yield and seed yield, but the proportion of TDM was higher than seed following application of N to legumes. The HI of the legumes is reduced due to a comparatively high increase in TDM production.

According to Reddy *et al*. (2003) any approach which promotes remobilization of photosynthates from vegetative to reproductive organs influences HI and thus productivity. Soil application of boron (2 kg/ha) at ray floret stage increased the HI to an extent of 29% and the seed yield by 53%. Boron is known to play an important role in translocation of sugars.

Mode of Inheritance of Harvest Index

The genetic control of harvest index plays an important role in improving crop productivity. The inheritance mode of harvest index was mainly by additive gene action, as was heading date, plant height, and 100 seed weight. Harvest index showed higher narrow sense heritability than plant weight and grain yield. Heritability of harvest index was highest in stress environments (Rosielle, 1975).

Monpara and Gaikwad (2014) stated estimates of heritability for HI were low to high (36.29-91.01%), where as those of genotypic coefficient of variation (GCV: 16.06-92.38%) and genetic advance (15.55-84.58%) were moderate to high in populations studied. However, moderate to high magnitude of heritability coupled with high genetic advance and high GCV in four out of six crosses indicated that the gene action governing the expression of HI was largely due to additive in nature and improvement in this trait is possible through selection.

Ur-Rehman *et al*. (2005) reported for harvest indexes both additive and non additive gene action was significant in both F1 and F2 generations of diallel analysis in mung bean. The relative contribution of   additive gene effect was more preponderant than non-additive in F1 while in F2 non additive gene action (dominance) was higher than additive genetic effect for harvest index in mung bean. Pinto Júnior *et al*.(2018) reported highly significant mean square of both GCA and SCA for HI in their study of diallel analysis griffing method II in common bean. They found average HI of F2, F3 and F4 ranged from 0.28 to 0.42 and 0.20 to 0.38 for parents and hybrids, respectively.

The mean square due to GCA and SCA was significant in both F1 and F2 progenies of a ten-parent diallel cross (excluding reciprocals) of hexaploid wheat for   harvest index and yield. However, the general combining ability (gca) component of variance was predominant than specific combining ability (sca) indicating the predominance of additive gene effects for these traits in wheat (Joshi *et al*., 2004). In line to this, Chand *et al.* (1996) found that additive gene action was important for the expression harvest index in wheat.

Conclusion

Harvest index (HI) is the proportion of percentage of grain yield to total biomass. It is a novel trait which directly

associated with yield, and the capacity of a crop for diverting the total dry matter into economic yield. The harvest index of different grain crops couldn't achieved to the range of upper limit value. Therefore, the objective of this paper was to review the role and progress of HI in improving crop productivity. The HI is variable to genetic factors and environmental factors. The genetic mode of expression of HI also substantially varies among crops which assist breeder to determine breeding strategy for enhancement of crop productivity. Improvement of this trait offer higher grain yield among some crop species. Hence, greater emphasis could be placed on breeding program for high harvest indexes for crop species to identify conditions and genotypes associated with a stable, higher harvest index and higher yield, simultaneously.

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