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Research Article

Determination of Critical Period of Weed-Crop Competition in Malt *Barley* (Hordeum *vulgare* L.) in North Showa Zone, Central Ethiopia

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Abstract

Weeds are the principal limiting biological factor in national barley production, with losses that vary from region to region, depending on the cultivation system, predominant weed communities and weed control methods employed by the farmers. Therefore, field experiment was conducted under rain fed conditions in 2017 cropping season to determine the critical period of Weed-Crop Competition in malt barely (Hordeum vulgareL.) at Debre Birhan University in North Showa Zone, Central highlands of Ethiopia. A total of eighteen treatments were laid out in a randomized complete block design (RCBD) with three replications. The treatments consisted of increasing duration of weedy and weed-free set each consisted weed competition and weed-free durations up to 20, 30, 40, 50, 60, 70, 80 and 90 days after crop emergence (DAE) were compared with two checks namely completely weedy and weed free up to harvest. The major weed families competing vigorously with barley were Compositae and Gramineae and Cyperaceae. According to the current study, the weed density and weed dry weight were decreased, whereas crop parameters like the number of days required to reach heading of barely, the number of days required to reach physiological maturity, number of seed per spike, spike length, thousand seed weight, aboveground dry biomass, grain yield and harvesting index of crop were highly increased, with increasing duration of weed-free periods. The highest yield loss due to weed competition from the weedy check treatment of barely as compared to weed free check. Uncontrolled weed growth significantly reduced barely grain yield by 70.38% compared to the grain yield obtained from the weed-free check plots. The beginning and the end of critical period of weed crop competition were based on 5 and 10 % acceptable yield loss levels, which were determined by fitting logistic and Gompertz equations to relative yield data, representing increasing duration of weed-interference and weed-free periods. In conclusion, the results of the study revealed that, to reduce the loss in the grain yield of barley by more than 10% and higher economic return, it is important to keep the crop weed-free between 33 to 49 days after crop emergence (639 to 1049 GDD) at Debre Berhan.

Keywords

Broad Leaved Weeds, Critical Periods, Competition, Gompertz Equation, Logistic Equation, Malt Barley, Yield Loss

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1. Introduction

Barley (*Hordeum vulgare* L.) is an annual cereal crop, which belongs to the tribe Triticeae of family Poaceae [1, 2]. It was one of the crops used in the beginning of the agriculture revolution [3]. Barley has a long history of cultivation in Ethiopia and it is reported to have coincided with the beginning of plow culture [4] and it is the fifth most cultivated crop of the world [5]. Barley is a cool-season crop that is adapted to high altitudes, grown in a wide range of agro climatic regions under at altitudes of about 1800-3500masl, which provides different uses [6]. Barley is used as a staple food, for malting and for making local drinks, and is sold for cash and straw and stem stubs are used for animal feed and thatching [7]. Because of its wide range of uses, barley is considered the "king of grains" in much of the country and low farm input supplies such as fertilizer and improved seed [8]. It covers 10% of the land under crop cultivation [9, 10].

In tropical Africa, Ethiopia is the only country where barley is a major crop, being the fifth most important crop both in area under cultivation and in production after teff, maize, sorghum and wheat [11] but third based on yield per unit area [12]. Ethiopia is the second largest producer of barley in Africa next to Morocco, accounting for about 26 percent of the total barley production in the continent [13].

In spite of the huge importance of barley as food and malt, its productivity is quite low in Ethiopia. The low productivity of the crop is associated with multidimensional abiotic and biotic factors [14, 15]. According to these authors, barley production in Ethiopia is constrained by several problems, such as poor soil fertility, water-logging, and moisture stress, low yielding potential of currently grown barley cultivars and instability of yield because of diseases, insect pests and weeds.

Weeds are a permanent constraint to crop productivity in agriculture. And they are plant, which compete for nutrients, space, light and exert lot of harmful effects by reducing the quality, as well as quantity of the crop, if the weed populations are left un-controlled [16, 17]. Weeds that are most competitive have rapid seedling growth and a high growth rate compared to the crop with which they are interfering [18]. Compention is negative interactions where individuals make simultaneous demand that exceed limited resource and, while both suffer; one individual suffers less [19]. So, crop weed competion indicates competion between crop and weed in a natural ecosystem in response to resource struggle for their existence and superiority.

Poor weed control in cereals can lead to considerable yield losses, make harvesting difficult and is visually undesirable. In addition, poor control in one season can lead to problems with increased weed populations in subsequent crops [20]. Stroud [21] also informed that the average yield loss in barley was very high, when the crop has received no weed control. Weed control has been observed as one of the most important practice in crop production because good Weed control will ensure maximum yield and high quality of farm produce [22].

The principles of integrated weed management (IWM) should provide the foundation for developing optimum weed control systems and efficient use of herbicides [23]. The critical period for weed control (CPWC) is a key component of an IWM program. It is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses [24, 25]. Controlling weeds based on CPWC is the most appropriate way to optimize weed control applications [23]. With the aid of CPWC it is possible to make decisions on the need for and timing of weed control and to control weeds only when efficient weed control is required [26, 27]. Studies on CPWC have been reported comprehensively in many crops in varying environments; but, studies on CPWC on barley are limited in Ethiopia in general and in North Shoa, 'Basso' Woreda in particular. Therefore; the present study is initiated to determine the critical period of weed-crop competition and yield loss in barley (Hordeum vulgare L.).

2. Material and Methods

2.1. Description of the Study Area

The experiment was conducted in the central high land of Ethiopia, North Shewa Zone 'Basso 'Woreda, at Debre Berhan during the 2017 main cropping season. The area is located at 9^{0} 30' N latitude and 39^{0} 38' E longitudes and an altitude of 2780m above sea level which is about 130km north east of Addis Ababa. The area receives mean annual rain fall of 1045.5 mm. The mean annual temperature is a maximum of 18.61 ℃ and a minimum of 5.2 ℃; with the coldest season occurring between October and January [28].

2.2. Treatments and Experimental Design

The experimental treatments were arranged following the method described by [29]. eighteen treatments in two series i.e. early (weedy up to 20, 30, 40, 50, 60, 70, 80 and 90 days after crop emergence and late (weed free up to 20, 30, 40, 50, 60, 70, 80 and 90 days after crop emergence competition periods were compared with two checks namely complete weed free and weedy check. The design of the experiment was randomized complete block design with three replications. The treatments were assigned to each plot randomly. The area of each plot was 2.4m by 3m and each plot was consist of 10 rows with row spacing of 0.3m. The frequency of weeding on the weed-free plots was based on the appearance of weeds.

Growing degree days (GDD), which was used as an independent variable in regression analysis, was calculated as:

GDD=Σ (Daily average temperature-Base temperature).

The base temperature used in the calculation is 10 ℃.

2.3. The Experimental Materials

The malt barley variety (Holker) which is adapted to the agro-ecology of the area was used for the study.

Table 1. Description of malt barley variety used for the experiment.

Name of variety	Altitude adaptable (m.a.s.l)	Rainfall amount (mm)	Day to maturity	Year of release	Yield kg ha-1 in research field
Holker	2300 – 3500	500 - 700	135 – 141	_	2400 - 3800

Source: Barley Production Package, 2015.

2.4. Data Collection

2.4.1. Weeds Data

Weed flora: Data on weed flora present in the experimental fields were recorded during the experimental period. The weed species found within the sample quadrate will be identified and classified into their respective groups.

Weed density: The weed density were recorded by throwing a quadrate (0.25 m ×0.25 m) randomly at two places in each plot at the time of weed removal for early competition and about 15 days before the expected harvest time in the case of late competition to avoid possible foliage and seed shading. The weed species found within the sample quadrate were identified, counted and expressed in m^{-2}.

Weed aboveground dry biomass (g): For aboveground weed dry biomass, the weeds falling within the quadrate were cut near the soil surface immediately after recording data on weed count and placed into paper bags separately treatment-wise. The samples were sun-dried for 3-4 days and thereafter will be placed into an oven at 65°C temperatures till a constant weight and, subsequently, their dry weight was measured. The dry weight was expressed in g m^{-2}.

2.4.2. Crop Data

Number of days to 50% heading: This parameter was recorded as number of days from emergence of barley to the first flower appeared on 50% of the plants in each plot.

Days to physiological maturity: It was recorded as the number of days from emergence to the day when 85% of the plants reached physiological maturity, *i.e.* both panicles and plants turned yellow (senescing) based on visual observation.

Plant height (cm): It was taken with a ruler from 10 randomly taken and pre tagged plants in each net plot area from the base to the apex of the main stem at physiological maturity.

Number of productive tillers per plant: 10 plants were taken at random from each plot and total number of productive tillers per plant was recorded.

Spike Length per plant: Measurement was taken from basal node of the rachis to apex of each panicle. Each observation was on average of 10 plants.

Number of seed per spike: The numbers of seeds of each of the 10 randomly taken plants for each experimental plot were counted and the average was used for analysis.

Thousand seed weight (g): 1000 seeds were counted and their weight was recorded at 10.5% moisture content for thousand seed weight.

Aboveground biomass (g): This parameter was determined by harvesting ten plants in each plot at physiological maturity and their dried aboveground biomass was recorded. Treatment-wise per plant dry weight of straw was multiplied by the number of plants in respective treatments. This was considered as the aboveground dry biomass weight.

Grain yield (kg ha^{-1}): The grain yield was measured after threshing the sun-dried plants harvested from each net plot and the yield was adjusted at 12.5% seed moisture content. The grain weight obtained in ten plants was added to the final yield.

Harvest index (%): This parameter was calculated by dividing the grain yield by the aboveground biomass yield and multiplied by 100.

Logging problem (%): this parameter was recorded by observing of plants log in the soil after the weed removed.

The maximum barley yield loss due to weed competition was calculated as:

$$Y = 1 - \left(\frac{\text{barley yield in weedy check}}{\text{barley yield in weed free check}}\right) \times 100) \qquad (1)$$

2.5. Data Analysis

Data on weed density, weed dry biomass; crop phenology, growth, yield attributes and yield were subjected to analysis of variance (ANOVA) using SAS computer software [30]. Fisher's protected least significant difference (LSD) tests at p≤0.05 were used to separate differences among treatment means [31].

To calculate the critical period of weed control in barley, the relative barley yield (*Y*) of each treatment was calculated as:

$$Y=\left(\frac{\text{barley yield in treatment}}{\text{barley yield in weed free check}}\right) \times 100) \qquad (2)$$

And non-linear regression equations were used to fit the data using STATISTICA software [32].

The onset and end of critical period, which is the duration mandatory for controlling weeds was estimated by the response curve when both curves attained 90% of the relative yield gain and 10% of the yield loss of the complete weed-free period. The critical period was determined and found to be in between these two threshold points.

Analysis was based on the models suggested by [26]. The Gompertz equation was used for describing the effect of increasing duration of weed control on barley yield and the logistic equation was used for describing the effect of increasing duration of weedy period on barley yield. The Gompertz equation used was:

$$Y = a\exp\left[-b\exp\left(-k\ T\right)\right] \qquad (3)$$

Where *Y* is relative yield, *a* is the yield asymptote, *b* and *k* are constants, and *T* is the time (x-axis expressed in GDD). The logistic equation used was:

$$= \left[\left(\frac{1}{\{\exp(c*(T-d)]+f\}}\right) + \left(\frac{(f-1)}{f}\right)\right] \times 100 \qquad (4)$$

Where *Y* is relative yield, *T* is the time (x-axis expressed in GDD); *d* is the point of inflection, *c* and *f* are constants.

2.6. Partial Budget Analysis

The partial budget analyses were done to determine the profitability of the weed control treatments. It was calculated by taking in to account the additional input cost (variable cost) involved and the gross returns obtained from different weed control treatments. The variable cost also included the labor cost involved from land preparation to harvesting, threshing and winnowing (estimated) of the produce, as this will vary according to the yield obtained in a particular treatment. For determining gross returns, the prevailing local market price at the harvest of barley was taken. The net returns will be calculated by subtracting the cost of treatment from the gross returns as described by [33].

RNR= GR – VC: Where, RNR= Relative Net Return

GR= Gross return and
VC= Variable Cost

3. Result and Discussion

3.1. Weed Parameters

3.1.1. Weed Community

The major weeds in the experimental fields were broadleaved, grassy and while sedges were found to a lesser extent (Table 1). Nineteen weed species found infesting the experimental fields belonged to thirteen families. The major weed families competing vigorously with barley were Compositae (4) and Gramineae (2) and Cyperaceae (2). The weed flora present in the experimental fields is presented in table 1.

Table 2. *Weed community recorded in barley field at the experimental site in 2017 cropping season.*

Weed species	Family	Life form (category)
Anthemis tigreensis	Compositae	Broad leaved (annual)
Argemone mexicana *L.*	Papaveraceae	Broad leaved (annual)
Avena fatua L.	Gramineae	Grassy (annual)
Chenopodium opulifolium Schr.	Chenopodiaceae	Broad leaved (annual)
Galium spurium L.	Rubiaceae	Broad leaved (annual)
Corrigiola capensis L.	Caryophyllaceae	Broad leaved (annual)
Cynadropsis gynandra L.	Capparidaceae	Broad leaved (annual)
Cyperus assimilis Steud	Cyperaceae	Sedge (annual
Cyperus esculentus L.	Cyperaceae	Sedge (perennial)

Weed species	Family	Life form (category)
Digitaria abyssinica L.	Gramineae	Grassy (perennial)
Erucastrum arabicum L.	Cruciferae	Broad leaved (annual)
Euphorbia hirta L.	Euphorbiaceae	Broad leaved (annual)
Galinsoga parviflora L.	Compositae	Broad leaved (annual
Guizotia scabra (Vis.) Chiov.	Compositae	Broad leaved (annual)
Hibiscus trionum L.	Malvaceae	Broad leaved (annnual)
Medicago polymorpha L.	Leguminosae	Broad leaved (annual)
Polygonum nepalense L.	Polygonaceae	Broad leaved (annual)
Spergula arvensis L.	Caryophyllaceae	Broad leaved (annual)
Stellaria media	Caryophyllaceae	Broad leaved (annual)

3.1.2. Weed Dry Biomass

The analysis of variance showed very highly significant difference of durations on the weed competition periods in affecting weed dry weight of broad leaved weeds (Table 3). According to the result broad leaved weed dry weight was increased with increasing duration of weedy periods (IDWP) and decreased with the increasing duration of the weed free periods (IDWFP). This showed that with increasing duration of the weedy period the broad leaved weeds might have severely strived and utilizes the environmental resources perfectly for longer period of time and accumulated higher dry matter. On the other hand, in increasing duration of weed free periods the broad leaved might have grown in stress whereas the barley crop might have severely competed and use the environmental resources perfectly as compared to the weed. Due to sever competition of the crop the broad leaved weeds accumulate less dry mater. Treatments left weedy until 50, 60, 70, 80, 90 days after emergence (DAE) and weedy check produced higher dry biomass weight with values 294, 235, 290, 318, 291, 311gm^{-2} respectively, whereas plots left weed free until 90 DAE and weed free check produced lower dry weight with values 1.67 and 0 gm^{-2}. Dry weight of broad-leaved weeds (gm^{-2}) at the end growing seasons was significantly reduced by increased weed free period, The lowest broad leaved weeds dry biomass weight was found in (gm^{-2}) at 20 DAE under IDWP with the value of 10.78gm^{-2} and 1.67gm^{-2} under IDWFP (Table 3). The highest broad leaved weeds dry weight was found at 80 DAE and weedy check under IDWP. In IDWFP the highest broad leaved dry weight was found at 20 DAE and 30 DAE. The result of the preset study is similar with [34] who found that by increasing weed crop competition duration increased weed biomass. The maximum weeds in weedy check and minimum in weed free plots has also been reported by [35] for linseed crop and [36] for and black seed.

Grassy and sedge weed species were small components of the weed population in the experimental field. The dry weight of grass and sedge weeds (gm^{-2}) at the end of the growing season significantly affected by period of weed free (early weed removal) and weed infestation treatments (late weed removal) as compared to the weed infestation for whole season (weedy check). The maximum weed dry weight of grass and sedge weeds recorded at the weedy check treatment with values of 2.11 gm^{-2} and 2.58 gm^{-2} respectively (Table 3). Weed dry weight decreased significantly with the successive increases in the weed-free period. Similar result was reported by [37] and [38] who observed that weed density and dry weight decreased with increasing duration of weed-free period in an experiment conducted to determine the critical period of weed control in rice. The results are in accordance with those of [36] and [39] who reported that an increase in weed dry weight with increased competition periods in black seed and fennel crops respectively. [40] Also reported that the dry matter production in rice decreased due to weed competition as a consequence of disturbance in nutrient supply and distribution, lower water potential which resulted in reduced growth and straw production.

Table 3. *Effect of increasing duration of weedy and weed-free periods on weed dry weight (g m-^{2}) for broad leaved, grass, sedge weeds of barley at Debre Berhan University in 2017/2018 cropping season.*

Treatments	Weed dry weight for broad leaved (g m-^{2})	Weed dry weight for grass (g m-^{2})	Weed dry weight for sedge (g m-^{2})
DAE			
IDWP			
20	10.78^{hi}	1.15(0.85)^{cdefg}	1.39 (1.46)^{bcde}
30	38.45^{fgh}	1.17(0.98)^{bcdefg}	1.46 (1.79)^{bcd}
40	49.42^{f}	1.26(1.30)^{bcde}	1.77 (2.74)^{bc}
50	294.3^{c}	1.13(0.87)^{cdfeg}	1.22 (1.12)^{def}
60	235.22^{b}	1.35(1.32)^{bcd}	1.17 (0.93)^{defg}
70	290.83^{a}	1.17(0.97)^{bcdefg}	1.25 (1.12)^{def}
80	318.64^{a}	1.24(1.2)^{bcdef}	1.37 (1.65)^{cde}
90	291.49^{a}	1.22(1.02)^{bcdef}	0.82 (0.18)^{fgh}
WC	311.1^{a}	2.11(3.94)^{a}	2.58 (6.18)^{a}
IDWFP			
20	159.89^{d}	1.63(2.3)^{ab}	1.80(2.75)^{bc}
30	138.23^{de}	1.35(1.38)^{bcd}	1.43(1.56)^{bcd}
40	117.73^{e}	0.96(0.44)^{cdefg}	0.96(0.45)^{efgh}
50	44.67^{fg}	1.41(1.5)^{bc}	1.82(2.85)^{b}
60	25.18^{fghi}	0.95(0.41)^{cdefg}	1.07(0.67)^{defgh}
70	19.77^{ghi}	0.91(0.34)^{defg}	0.93(0.39)^{fgh}
80	19.81^{ghi}	0.76(0.08)^{fg}	0.71(0)^{h}
90	1.67^{i}	0.84(0.21)^{efg}	0.74(0.05)^{gh}
WFC	0^{i}	0.71(0)^{g}	0.71(0)^{h}
LSD (0.05)	28.01	0.75	1.30
CV (%)	13.44	24.41	20.53

DAE = Days after crop emergence; IDWP = Increasing duration of weedy period; WC = Weedy check; IDWFP = Increasing duration of weed-free period; WFC = Weed-free check; Means followed by the same letters within each column are not significantly different

3.2. Crop Parameters

3.2.1. Days to Heading

The effect of different competition durations was significant on days to heading of the crop (Table 4). In the increasing duration of weed free period (IDWFP) treatments (70, 80, and 90) DAE and weed free check, early heading of barely crop was observed whereas late heading of the barley crop was observed in the increasing duration of weedy period (IDWP) at 90 DAE and weedy check (Table 4).

3.2.2. Days to 90% Physiological Maturity

According to the result there were very highly significant differences among the durations of the weed competition treatments in affecting days to physiological maturity (90%) (Table 4). On the other hand, there were no any significant differences in days to physiological maturity when treatments of weed free until 50 to 90 days after emergence (DAE) and weed free check. There was also no significant difference among the weedy plots from 70 to 90 DAE and weedy check in affecting days to physiological maturity of barley (Table 4).

Table 4. *Effect of increasing duration of weedy and weed-free periods on days to 50% heading, days to 90% maturity of barley at Debre Berhan University in 2017cropping season.*

Treatment	Days to 50% heading	Days to 90 % maturity
DAE		
IDWP		
20	72.67[abcdef]	144.33[ab]
30	72.67[abcdef]	133[e]
40	74.67[abcd]	143.67[ab]
50	74.67[abcd]	137.67[cd]
60	76.33[ab]	137.67[cd]
70	75.33[abc]	145[ab]
80	76.33[ab]	144[ab]
90	77[a]	145[ab]
WC	77[a]	147.33[a]
IDWFP		
20	76.67[a]	144.33[ab]
30	76[ab]	138[c]
40	73.67[abcde]	141[bc]
50	71.67[abcdef]	132[e]
60	70.67[bcdef]	133[e]
70	69.67[cdef]	132.67[e]
80	69.33[de]	131.33[e]
90	67.67[ef]	132[e]
WFC	68.33[f]	130[e]
LSD (0.05)	5.68	4.37
CV	4.67	1.91

DAE = days after crop emergence; IDWP = Increasing duration of weedy period; WC = Weedy check; IDWFP = Increasing duration of weed-free period; WFC = Weed-free check; Means followed by the same letters within each column are not significantly different

3.2.3. Plant Height

The result showed that there were significant differences among the duration of weed competition treatments on plant height of barley (Table 5). The maximum plant height was recorded in the weed free check with value of 107.27 cm which was statically at parity with competition period of 90 days after emergence (DAE). The minimum plant height was recorded from the weedy treatment weedy until 90 DAE with value of 93.41 cm which was statically at parity with weedy check (Table 5). According to the result, plant height of barley crop decreased within increasing duration of weedy periods (IDWP) and increased with the increasing duration of weed free periods (IDWFP). This could be due to the fact that controlling the weeds from interfering with the crop for a long time resulted in significantly lower weed dry matter and resulted minimum competition between the weeds and the barley for growth resources particularly for light, moisture, soil nutrients and assimilate which promoted better crop growth performance. On the other hand in increasing duration of weedy period resulted in sever competition for the environmental resources. Such limited light, water, nutrients might have been taken by the weeds for longer period of time that reduced the plant height of barley crop. On other hand, with increasing duration of weed free periods such environmental resources might have been fully utilized by the barley crop for long period of time and resulted in increase in plant height of the crop.

The results also showed that treatments left weed free for the whole season resulted in increased in plant height of barely. On the other hand, treatments left weedy for the whole season resulted in decreased in plant height of barley. These results are supported by [41] who reported decrease in plant height of maize with increase in competition duration. The result of the present study is also similar with those of [36] who reported lower plant height in black seed with increased competition periods. The results are however, in contrast with those of [39] who reported an increase in plant height of fennel (*Foeniculum vulgare* Mill.) with increase in competition period from 50 to 80 days after sowing. According to [42] the taller rice plants were found in all weed-free treatments. [43] also pointed that the plant height of rice decreased when weeds were allowed to compete till 30 DAT and up to harvest. [44] also observed that the plant height of rice significantly reduced when rice plant competed with *Fimbristylis miliacea* for 70 days or longer. Similarly, [45] noted that plant height of rice was significantly reduced by competition with jungle rice (*Echinochloa colona*), and the reduction was increased in higher weed density. [46] reported that rice plant height was significantly decreased with weed competition for 40 days or longer.

3.2.4. Number of Tillers Per Plant

Very highly significance difference was observed among the duration of weed competition on number of productive tiller per plant (Table 5). In increasing duration of weedy period treatments weedy check had the lowest number of productive tillers per plant (3.87), which was in statistical parity with the number of productive tillers per plant at 70, 80, and 90 DAE. In increasing duration of weed free period treatments weed free check had the highest number of productive tillers per plant (13.9), which was in statistical parity with the number of productive tillers per plant at 60, 70, 80, 90 DAE (Table 5). There was no significance difference between treatments in IDWP at 60-90 DAE and weedy check. There was also no significance difference between treatments in IDWP at 20 DAE and 30 DAE. In IDWFP the productive tillers were high. This was because of the environmental resources was taken by the plant for long period of time. In general the number of productive tiller number decreased in IDWP and the number of productive tiller number increased in IDWFP (Table 5). This could be because weeds were removed, which could have minimized weed competition and enhanced the utilization of growth resources for optimal production of photosynthesis for better performance. The result indicated that the effective tillers of rice were adversely affected by increasing the length of weed interference period which might be due to reduce the ability of rice to compete for light and nutrition and increasing the disadvantage of the crop in weed competition [47]. The results are in accordance with the findings of [43], who argued significant decrease in tiller numbers with weed competition period during 45 DAS to harvest. [48] Pointed out that the tillers numbers of rice were significantly affected by the weeding competition period, both in saturated and flooded conditions. Similarly, [44] found that the number of effective and total tillers decreased with onset of competition from 42 days until the crop harvest.

3.2.5. Spike Length Per Plant

Very highly significance differences were observed among the duration of weed competition on spike length per plant (Table 5). The highest spike length was obtained from the weed free treatments in weed free for whole season followed by weed free until 90 DAE with value of 9.19 cm and 9.05cm respectively. Weed infestation for whole season caused reduction spike length compared to weed free for the whole season. There was no significance difference between treatments in IDWP at 50, 60, 70, 80, 90 DAE and weedy check. There was also no significance difference between treatments in IDWFP at 50, 60, 70, 80, 90 DAE and weed free check (Table 4). Plots left weedy for long period of time caused for decreased in the spike length of the plant and vice versa (Table 4). This was due to in IDWP the ability of the weed to utilize the environmental resources limited light, water, nutrients was high rather than the crop plant and the plant grow in stress. In agreement with this result, [49] reported that panicle length per plant increased as weed interference period decreased and weed-free period increase.

3.2.6. Number of Seed Per Spike

Very highly significance difference was observed among the duration of weed competition on number of seed per spike (Table 5). Number of Seed per spike of barely crop was affected significantly by weed crop competition periods during 2017 cropping season (Table 5). On the other hand, no significant differences existed in number of seed per spike when plots were allowed to be weedy at 50 to 90 DAE and weedy check. There was also no significant difference among weed free plots from 50 to 90 DAE and weed free check. The weedy plots from 50 to 90 DAE were also in statistical parity among each other.

The maximum number of number of seeds per spike was recorded in weed free treatment at 60 DAE with the value of 29.97. The minimum number of number of seeds per spike was recorded in weedy treatments at 90 DAE with the value of 17.3 (Table 5). The minimum number of seeds per spike was due to augmented competition between weeds and crop plants throughout the life span. The depletion of resources by weeds resulted in scarcity of resources and ultimately crop plants had less number of seed per spike. A decrease in fruit bearing ability of fennel plants with intensification in competition period has also been discovered by [39]. These are in accordance with [50]. He found that increase in weed competition duration decreased the number of grains per ear. Higher seed yield in weed free plots has also been reported by [35, 51, 39]. [52] also report similar results. Reported that number of tillers per plants significantly increased with increasing length of weed-free period and decreased with increasing length of weed infested period in common bean.

Table 5. *Effect of increasing duration of weedy and weed-free periods on plant height (cm), number of tiller number, spike length (cm) per plant and number of seed per spike of barley at Debre Berhan University in 2017 cropping season.*

Treatments	Plant height (cm)	Number Tillers per Plant	Spike length (cm) per Plant	Number of Seed per Spike
DAE				
IDWP				
20	100.28^{abcd}	10.53^{d}	7.77^{bc}	25.67^{bc}
30	100^{abcd}	10.33^{d}	6.58^{efd}	21.73^{de}
40	95.37^{d}	8.17^{ef}	6.42^{ef}	21.83^{de}
50	96.27^{cd}	8.33^{e}	5.76^{gf}	20.1^{ef}
60	96.83^{cd}	6.6^{fg}	5.81^{fg}	20.03^{ef}
70	96.21^{cd}	5.17^{gh}	5.20^{g}	18.1^{f}
80	96.23^{cd}	5.4^{gh}	5.09^{g}	17.77^{f}

Treatments	Plant height (cm)	Number Tillers per Plant	Spike length (cm) per Plant	Number of Seed per Spike
90	93.41^{d}	4.63^{h}	5.02^{g}	17.3^{f}
WC	93.53^{d}	3.87^{h}	5.73^{fg}	19.27^{ef}
IDWFP				
20	98.5^{bcd}	7.1^{ef}	7.34^{bcd}	24.43^{cd}
30	100.43^{abc}	10.33^{d}	7.48^{bcd}	24.3^{cd}
40	101.45^{abcd}	11.6^{bcd}	8.38^{ab}	27.5^{ab}
50	104.83^{abc}	10.73^{cd}	8.78^{a}	29.4^{a}
60	106.15^{ab}	12.3^{abc}	8.99^{a}	29.97^{a}
70	106.41^{ab}	12.3^{abc}	8.75^{a}	29.3^{a}
80	107.18^{a}	12.73^{ab}	8.8^{a}	28.87^{a}
90	107.18^{a}	12.2^{bc}	9.05^{a}	29.53^{a}
WFC	107.27^{a}	13.9^{a}	9.19^{a}	29.57^{a}
LSD (0.05)	8.80	1.61	0.93	2.88
CV	5.29	10.52	7.76	7.18

DAE = days after crop emergence; IDWP = Increasing duration of weedy period; WC = Weedy check; IDWFP = Increasing duration of weed-free period; WFC = Weed-free check; Means followed by the same letters within each column are not significantly different

3.2.7. Thousand Seed Weight

The result of the present study showed that increasing duration of weed-free period significantly affected thousand seed weight of barley (Table 6). In IDWFP, weed free (WF) until 90 days after emergence (DAE) had the highest thousand seed weight (74.05 g). On the other hand, there was no significance difference among treatments of weed free in affecting thousand seed weight of barley until 50 to 90 days after emergence (DAE) except the weed free until 60 DAE. In IDWP, the weedy check resulted the lowest thousand seed weight (60.73g) of barley. According to the result, thousand seed weight was decreased with the increase in the duration of weedy periods and increased with increase in the duration of weed-free periods. This could be due to the decrease in interference of the weed with the crop for a long time. Similar to this finding, [37] and [38] also reported that thousand seed weight were increased with the increasing length of weed-free conditions and decreased with the increasing length of weedy conditions. The significant difference in seed weight of black seed due to weed competition has also been reported by [36].

3.2.8. Above Ground Dry Biomass Yield

According to the result, highly significant differences were observed among the duration of weed competition treatments on above ground dry biomass (Table 6). Based on the observed data aboveground dry biomass yield of barley was significantly influenced both by the increasing and decreasing periods of weed competition. By increasing the duration of the weedy period (IDWP) no significant difference were observed among 20 to 50 DAE and 80 DAE treatments. Similarly, by increasing duration of weed free period (IDWFP) no significant difference were observed among the 20 DAE and the weed free check treatments. According to the result, the lowest above ground dry biomass of barley was observed in the weedy until 90 days after emergence (DAE) with the value of 7063 kg ha^{-1} and statistically parity with the aboveground dry biomass yield obtained from plots which were kept weedy for 70 DAE and weedy check (Table 6). In line with the current finding, [37] reported that adverse effect of increasing weedy period on biomass production increased gradually with the advancement of growth stages. In increase duration of weed free period (IDWFP), the lowest dry biomass (10000kg ha^{-1}) was recorded in plots which were kept weed-free up to 90 DAE.

3.2.9. Grain Yield

The result showed that there were very highly significant differences among the duration of weed competition treatments on grain yield of barley (Table 6). Based on the result, the maximum grain yield (5595 kgha^{-1}) was recorded from the weed free check. The grain yield obtained from the weed free check plot was in statistical parity with the yield obtained from the weed free plots until 70 to 90 DAE, under the increasing duration of weed free period. The minimum grain yield (1666.7 kg ha $^{-1}$) was recorded from the weedy check. In IDWP, weedy until 90 DAE also produced the lowest grain yield (2119kg ha^{-1}), but the yield did not differ significantly with the yield obtained from the plots that remained weedy up to 70 DAE with the value of 2142.9 kg ha^{-1} (Table 6).

Table 6. *Effect of increasing duration of weedy and weed-free periods on, above ground biomass yield, Grain yield per hectare and thousand seed weight (g m^{-2}) of barley at Debre Berhan University in 2017cropping season.*

Treatments	Above ground biomass yield (kg)	Grain yield (kg ha^{-1})	Thousand seed weight (g m^{-2})
DAE			
IDWP			
20	9365[cde]	3579.4[de]	68.23[bcd]
30	10635[bdc]	3023.8[efg]	68.87[bc]
40	11905[ab]	3968.3[cde]	66.79[cde]
50	10476[bcd]	3246[ef]	66.89[cd]
60	9127[def]	2420.6[fgh]	63.69[fg]
70	8095[ef]	2142.9[gh]	65.49[ef]
80	10556[bd]	2309.5[fgh]	62.26[gh]
90	7063[f]	2119[gh]	61.86[gh]
WC	9048[def]	1666.7[h]	60.73[h]
IDWFP			
20	10317[bcd]	2500[fgh]	66.48[de]
30	13095[a]	4436.5[bcd]	67.35[cde]
40	11190[abcd]	3849.2[de]	68.83[bc]
50	11508[abc]	3952.4[cde]	72.65[a]
60	10159[bcde]	4222.2[bcd]	70.14[b]
70	11508[abc]	4952.4[ab]	73.24[a]
80	11746[ab]	5412.7[a]	72.54[a]
90	10000[bcde]	4857.1[abc]	74.05[a]
WFC	10635[bcd]	5595.2[a]	73.4[a]
LSD (0.05)	0.93	949.6	2.21
CV	12.88	16.03	2

DAE = days after crop emergence; IDWP = Increasing duration of weedy period; WC = Weedy check; IDWFP = Increasing duration of weed-free period; WFC = Weed-free check; Means followed by the same letters within each column are not significantly different

In increased duration of weedy period (IDWP), the grain yield declined significantly. The decrease in grain yield of barley with the increase in the duration of competition might be the result of increased weed dry weight of weeds which might have influenced the number of tillers per plant, spike length per plant, seed per spike and in general yield components of the plant. Barley grain yield decreased with prolonged delays in weed removal; conversely, grain yield increased with the increasing length of weed-free period. These results may be due to improved growth characters of barley crop plants such as tiller number per plant, spike length per plant, seed per spike and spike weight per plant, due to decreased weed competition for barley crop plants. These results are supported by those of [53] and [54]. They found that wheat yield decreased as the weed infested duration increased. It has also been reported that grain yield significantly reduced by increasing the weed competition duration of *Fimbristylis miliacea* [42]. Similarly, [55] reported that rice grain yields were significantly affected by weeding interval treatments in both saturated and flooded conditions. Rice grain yield was drastically decreased in saturated condition as a consequence of increasing the weed infestations [56]. [57] reported as high as 95% yield reduction in rice due to weed competition throughout the rice growing season.

3.2.10. Harvest Index

Very highly significance difference was observed among the duration weed competition on harvest index (Table 7). In IDWP treatments, no significant difference were found between weedy until 30 DAE, 60 to 90 DAE and weedy check except weedy until 80 DAE. Similarly, no significant difference was observed between 40 and 50 DAE. In IDWFP treatments, no significance difference was observed between 40 and 50 DAE. In IDWP the lowest harvest index (21.90%) was recorded in the weedy until 80 DAE plots, in statistical parity with the harvest index obtained in plots kept weedy for 90 DAE and weedy check. In IDWFP the maximum mean harvesting index (48.21%) was recorded in weed free check plots, in statistical parity with the harvest index obtained in plots kept weed free for 80 and 90 DAE (Table 7).

3.2.11. Logging Percentage

Highly significance difference was observed among the duration weed competition on logging problem per plot (Table 7). In IDWP, weedy until 90 DAE had the highest logging problem per plot (18.33). The probable reason might be due to the weakness of the crop as a result of maximum competition when the crops were kept weedy for longer periods and the weak cannot stand alone after weed removal. On other hands there was no significance difference between treatments in weed free until 20 to 90 DAE, weed free check and in weedy plots weedy until 20 DAE, 30 DAE and weedy check. There was also no significance difference between treatments weedy until 60 to 80 DAE and 70 to 90 DAE. But there is a significant difference between treatments weedy until 60 DAE and weedy until 90 DAE (Table 7).

3.2.12. Yield Loss

According to the result, there were very highly significant differences among the duration of weed competition treatments on grain yield loss of barley (Table 7). In the increased duration of weedy period (IDWP), the highest yield loss was recorded in weedy check followed by weedy until 90 DAE whereas in the increased duration of weed free period (IDWFP), the lowest yield losses were recorded in the weed free check and weed free until 80 days after emergence (DAE). The grain yield losses seem to be much higher in high weed densities. The barley grain yield losses in the weedy check and weedy until 90 DAE as compared to the weed-free checks were 70.38% and 62.07%. These values are very close to those reported in a previous study, where season long weed competition reduced yield by approximately 50% [58]. [48] recorded 79 and 66% yield reduction in rice due to weed competition till harvest in flooded and saturated conditions, respectively. [57], on the contrary, reported as high as 95% yield reduction in rice due to weed competition throughout the crop growing season.

Table 7. *Effect of increasing duration of weedy and weed-free periods on harvesting index (%), logging problem and yield loss of barley at Debre Berhan University in 2017cropping season.*

Treatments	Harvesting index (%)	Logging problem (%)	Yield loss (%)
DAE			
IDWP			
20	36.07^{cdef}	0.33^{e}	35.80^{de}
30	26.29^{gh}	1.67^{de}	45.57^{bcd}
40	30.30^{fg}	2.67^{d}	29.98^{def}
50	30.51^{fg}	5^{c}	41.93^{cd}
60	26.54^{gh}	15.67^{b}	56.67^{abc}
70	26.48^{gh}	17^{ab}	61.81^{ab}
80	21.90^{h}	16.33^{ab}	58.77^{abc}
90	24.81^{gh}	0.33^{e}	62.07^{ab}
WC	24.51^{gh}	18.33^{a}	70.38^{a}
IDWFP			
20	24.63^{gh}	0^{e}	55.27^{abc}
30	26.29^{gh}	1.67^{de}	45.57^{bcd}
40	31.94^{defg}	0^{e}	30.83^{de}
50	32.05^{defg}	0^{e}	33.09^{de}
60	38.41^{bcde}	0.33^{e}	28.49^{def}
70	39.33^{bcd}	0.67^{de}	11.01^{gh}
80	41.93^{abc}	0^{e}	2.80^{h}
90	45.12ab	0^{e}	12.90^{fgh}
WFC	48.21^{a}	0^{e}	0^{h}
LSD (0.05)	7.65	2.26	17.37
CV	14.3	31.35	28.64

DAE = days after crop emergence; IDWP = Increasing duration of weedy period; WC = Weedy check; IDWFP = Increasing duration of weed-free period; WFC = Weed-free check; Means followed by the same letters within each column are not significantly different

3.3. Critical Periods of Weed Control

Critical period of weed control (CPWC) was determined by using relative barley yield (% of season long weed-free yield) and growing degree days (GDDs) as quantitative variables in the regression analysis. Barley emergence date was used as the reference point for accumulation of GDD for accounting the possibility of weeds emerging before the barley. The CPWC was determined based on arbitrarily chosen yield loss levels (AYL) of 5% and 10%, which are judged to be acceptable considering the present economics of weed control.

The Gompertz and logistic equations generally described the data well as indicated by high coefficients of determination (R^2) values (Table 8). The beginning of CPWC based on 10%AYL occurred by 639 GDD corresponding to 33 days after emergence (DAE) (Table 9). The end of the CPWC at 10% AYL occurred by 1049 GDD or 49DAE. At 5% AYL, the onset of CPWC occurred at 294 GDD, relating to 15DAE. Weeds had to be controlled until 1210 GDD, corresponding to 62DAE at 5% AYL.

A long critical period is the indication of less competitive crop or more competitive weeds and vice versa [59, 37, 48, 37] also estimated longer CPWC of rice in longer season both flooded and saturated conditions. [60], on the contrary, observed differences in CPWC between seasons in irrigated lowland rice. The onset of CPWC became delayed and ended earlier as the predetermined AYL increased from 5% to 10%. This finding is supported by many researchers [26, 61, 27, 37, 38] who indicated that the end of CPWC was variable and highly dependent on density, competitiveness, and emergence periodicity of the weed population.

Table 8. Parameter estimates for the Gompertz and logistic equations for relative yield.

Site	Gompertz parameters				Logistic parameters			
	A	b	k	R^2	c	d	f	R^2
Debreberhan	100.2	1.35	0.095	0.92	0.21	0.655	1.27	0.95

Table 9. The critical period of weed control (CPWC) calculated from Logistic and Gompertz equations at Debre berhan location during 2017 main cropping seasons.

Yield loss levels (%)	Debreberhan			
	Onset		End	
	GDD	DAE	GDD	DAE
5%	294	15	1210	62
10%	639	33	1049	49

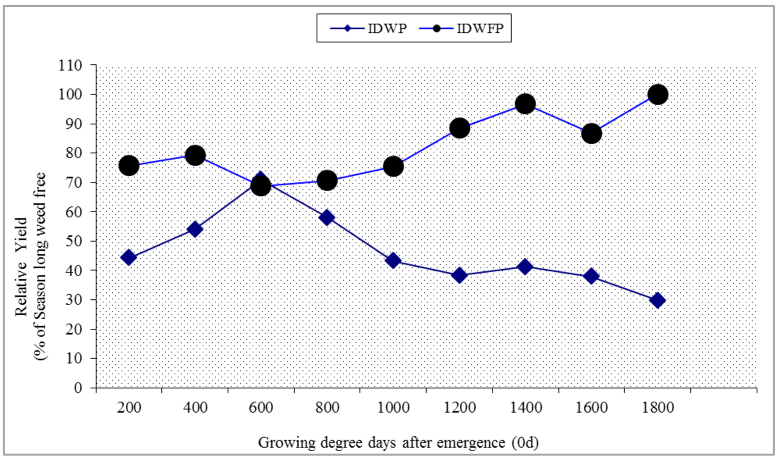

Figure 1. Effect of weed crop competition on relative barley yield at Debreberhan during 2017 main cropping season.

3.4. Partial Budget Analysis

The partial budget analysis was done as described by CIMMYT (1988) where the variable costs that vary included the cost of inputs as well as the cost involved in their application. The data used for the partial budget analysis is given in Table 10.

However, for ease in calculation in place of field price of the crop, the cost incurred for harvesting, threshing, winnowing, packing and transportation was added to the variable input cost. The yield difference per hectare recorded by the different treatments account for the variation observed in value of gross benefit. The partial budget analysis indicated that the highest gross benefit was obtained from IDWF at 80 DAE (72180.57 ETB ha^{-1}) followed by 70DAE (65736.14 ETB ha^{-1}) while the lowest price was recorded from weedy check plots.

Table 10. *Results of partial budget analysis of increasing duration of weedy and weed-free periods on in barley in 2017 main cropping season.*

Treatments	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1}) 10% down	Total variable cost (ETB ha^{-1})	Gross Return (ETB ha^{-1})	Net return (ETB ha^{-1})
IDWP					
20	3579.37	3221.43	8452.23	46513.90	41658.90
30	3023.81	2721.43	8122.23	38736.11	34211.11
40	3968.25	3571.43	7462.23	51958.32	48093.32
50	3246.03	2921.43	7132.23	41847.19	38312.19
60	2420.64	2178.58	6637.23	30291.68	27251.68
70	2142.86	1928.57	6142.23	26402.76	23857.76
80	2309.52	2078.57	5812.23	28736.90	26521.10
90	1666.67	1500.00	5482.23	19736.10	17851.10
WC	2119.05	1907.15	4327.23	26069.42	25339.42
IDWFP					
20	2500	2250.00	5647.23	31402.77	29352.77
30	4436.51	3992.86	6142.23	58513.86	55968.86
40	3849.21	3464.29	6802.23	50291.66	47086.66
50	3952.38	3557.14	7462.23	51736.09	47871.09
60	4222.22	3800.00	8122.23	55513.90	50988.90
70	4952.38	4457.14	8947.23	65736.14	60386.14
80	5412.7	4871.43	9277.23	72180.57	66500.57
90	4857.14	4371.43	9607.23	64402.78	58392.78
WFC	5595.24	5035.72	14557.23	74736.08	63776.08

4. Conclusions

Barley (*Hordeum vulgare* L.) is a cool-season crop that is adapted to high altitudes, grown in a wide range of agro climatic regions, which provides different uses. Barley is used as a staple food, for malting and for making local drinks, and is sold for cash and straw and stem stubs are used for animal feed and thatching. The filed experiments were conducted at Debre Berhan during 2017 cropping season. The aims of this study were to determine the critical period of weed-crop competition and yield loss in barley (Hordeum vulgare L.).

Knowledge of the best time for weed removal is limited. This knowledge is needed to change farmers' fatalistic attitudes about the yield depression that barley suffers as a result of weed growth. Information on the magnitude of yield losses incurred due to weed competition is essential to establish effective priorities aimed at promoting yield increases. Weeds are one of the most important factors contributing to the reduced productivity of barley in Ethiopia. It is clear that proper weed management can increase the productivity of the crop in general. The results showed that weeding had a greater influence on growth and yield of barley over no-weeding treatment. According to the result weed dry weight was increased with increasing duration of weedy periods (IDWP) and decreased with the increasing duration of the weed free periods (IDWFP). In the increasing duration of weed free period (IDWFP) treatments (70, 80, and 90) DAE and weed free check, early heading of barely crop was observed whereas late heading of the barley crop was observed in the increasing duration of weedy period (IDWP) at 90 DAE and weedy check. Plant height, number of productive tiller per plant, spike length, seed per spike of barley crop decreased within increasing duration of weedy periods (IDWP) and increased with the increasing duration of weed free periods (IDWFP). The depletion of resources by weeds resulted in scarcity of resources and ultimately crop plants had less thousand seed weight. According to the result, the lowest above ground dry biomass of barley was observed in the weedy treatments. In increased duration of weedy period (IDWP), the grain yield declined significantly. The highest yield loss was recorded in weedy check followed by weed until 90 DAE. The greatest harvest index was recorded by the weed-free treatment. Logging problem of barley crop was increased in IDWP.

The critical period for weed control (CPWC) is a key component of an IWM program. The results of this study indicated that the maximum barley yield losses due to the highest weed interference were 70.38% as compared to the weed free check. To prevent more than 10% yield loss, the efficient weed control methods for barley variety Holker could be accomplished by keeping the crop weed free between 33 to 49 DAE (639 to 1049 GDD) at Debre Berhan.

5. Future Research Direction

1) Further studies should be conducted to determine the critical periods in other areas, where weed populations are different from those reported at Debre Berhan.
2) Studies could be carried out to study the effect of weeding frequency on the yield of barley at different levels of soil fertility, with the aim to find out if the critical weed competition period is influenced by soil fertility, and if it is, to find out the required number of weeding at the optimal level of fertilizer application.
3) Studies could be carried out to study the efficacies of different weed control methods and/or their combinations should be evaluated in further studies to find out the most appropriate weed control strategy in barley during the critical period.
4) Further studies should be conducted to determine the qulity of malt barley for beer factory's.

Abbreviations

ANOVA	Analysis of Variance
CPWC	Critical Period of Weed Completion
CWFP	Critical Weed-free Period
DAE	Days After Emergence
GDD	Growing Degree Days
GR	Gross Return
IDWFP	Increasing Duration of Weed Free Periods
IDWP	Increasing Duration of Weedy Periods
IWM	Integrated Weed Management
LSD	Least Significant Difference
RCBD	Randomly Complete Block Design
RNR	Relative Net Return
VC	Variable Cost
WC	Weedy Check
WFC	Weed Free Check

Conflicts of Interest

The authors declare no conflicts of interest.

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