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ORIGINAL ARTICLE

Evaluation of potato (*Solanum tuberosum* L.) genotypes using different intercropping regimes

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ABSTRACT
Potato (Solanum tuberosum) an important vegetable crop grown around the globe. Present study was conducted to ascertain the effect of intercropping on potato tuber yield and its components. Intercrop versus no-intercrop potato with berseem crop was examined to find out yield performance of potato tuber lines. Experiment was a completely randomized design in factorial arrangement in three replications. Factors considered were intercropping (2) and advanced lines. An overall positive effect of intercropping was observed on tuber yield of potatoes genotypes. Tuber yield increased (18%) with intercrop. Additionally, there was a successive increase reported in yield components. Correlation analysis between various morphological and yield components was computed under both regimes. Tuber weight per plant showed a significant correlation with all traits excluding chlorophyll contents, leaf area, number of tubers per plant and harvest index in the intercrop. Tuber weight per plant showed a negative correlation with berseem weight. The association analysis displayed tuber diameter as an important trait under both regimes. Leaf area may be used to improve tuber diameter due to its positive correlation with tuber diameter and high value of heritability. The trait could also be used to discriminate the genotypes before the plants reach maturity.
Keywords: *berseem, biomass, nodulation, leaf area, tuber diameter, tuber yield*

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INTRODUCTION
Potato (*Solanum tuberosum* L.) is cultivated worldwide owing to its adaptability and primarily food of people in many countries. It is used in fresh form as vegetable and processed for industrial products [23, 16, 17, 21]. An appreciable amount of protein and energy per unit mass is present in potato when compared with wheat and rice. It is therefore, worth as a better staple food than other crops [14]. Increasing tuber yield is a primary goal of any potato breeding program and ambitious long term breeding objective. The availability of high yielding varieties could not only expand yield per unit area but also increases area under cultivation [7]. Researchers endure developing tuber varieties adapted to enviroments suitable for the high yield which rely mostly on heavy doses of the inputs. Due to the continuous increase in the input prices especially fertilizers, farmers are unable to fulfill the crop input requirements. The availability of atmospheric nitrogen by symbiotic nitrogen-fixing bacteria for the host and the following crop is another way to supply nutrients [2, 10]. However, it has been only utilized in nodulated crops. Nodulated crops may be grown in swards which may also supply useful nitrogen for the companion crop [10, 14].
Berseem (*Trifolium alexandrinum*L.) is luxurious fodder crop and its manyecotyes grown in Pakistn (Hussain *et al*., 2015). It being leguminous species is poor plant competitor and exert a positive effect on more input loving crops like potato by nitrogen fixation.
On the basis of these back ground, the experiment was carried out with the objectives to study the impact of intercropping on tuber yield and its component. Moreover, the screening of high yielding tuber population in their respective intercropping and non-intercropping regimes was carried out. The

criterion for selection of high yielding cultivars as an alternative for tuber yield per se was also defined on the basis of heritability and correlation with tuber yield.

MATERIAL AND METHODS

Plant Material

Twenty-threebreeding population of potato were received from the Potato research institute, Sahiwal, Pakistan and evaluated for two contrasting regimes i.e. potato populations were intercropped with berseem and without intercropping. Potato tubers of each population were cut into equal sizes and masses manually to have two nodes on each propagating seed with a sterile scalpel. All the cut tubers were inoculated with the fungicide.

Evaluation of Plant materials

The seeds of the 23 advanced lines of potato were sown on November10, 2015 in controlled conditions under completely randomized design with three replications having a factorial arrangement. The factors considered were intercropping (2) and advanced lines. Potato seeds were sown in large polythene bags of45 cm length×60 cm deep. Each polythene bag was filled with an equal mixture of sand and clay soil. The fertility of the soil was increased by adding 4 g of diammonium phosphate fertilizer to each bagpot. Two hoeing was done to check the growth of weeds. Temperature and humidity of the growth tunnel were determined at regular interval through hygro-thermometer. Relative humidity (40% ± 2) of the growth tunnel was controlled by opening the tunnels to allow passage of the air during peak photosynthesis hours while optimum temperature (25±2°C) was maintained throughout the growth cycle through natural sunlight trapped in the tunnel. Average humidity was maintained at 50% ± 5 during the entire crop growth season. Daily temperature and humidity were noted on the digital thermometer and hygrometer respectively installed within the tunnel. The controlled conditions were provided to facilitate the highest genetic potential under the near optimum condition and to avoid the confounding effects due to soil heterogeneity, chilling stress of winter season and frost damage. The contrasting intercropping regimes were created by sowing 2g inoculated seed of the berseem clover (*Trifolium alexandrinum* L.), variety agaitiberseem 15 days after the emergence of potato shoots. The seed of the berseem was inoculated with the 5 µL of rhizobium bacterial suspension (Rizobium leguminosarum bv.trifolii) before sowing. The non-intercropped regime did not receive the sowing of the berseem seed and only bacterial inoculum (1%) was provided along with irrigational water. All the accessions were evaluated for traits related to yield. Yield and yield components were determined at the time of maturity. The tubers of a particular accession were harvested when leaves became pale yellow. The polythene bags were gently cut with the sharp knife and soil was gently removed from each plant to harvest the tuber per plant.

Measurement of Plant Traits

The plant height was measured with a meter rod from the base of the stem and top axillary bud and values were shown in cm. Number of nodes plant^{-1}, number of tubers plant^{-1} or numbers of stems were counted manually. Leaf area (cm^2) was measured with a leaf area meter (CI-203, Cammas, USA). Chlorophyll contents were determined with chlorophyll meter (CL-01, chlorophyll meter, Hansatech Instruments, UK). Leaves were detached from the plant at the third node from the top of the canopy to determine leaf area and chlorophyll contents. Tuber weight per plant (g) was determined on field balance.

The plants were harvested and above ground biomass of each plant was also measured on the field digital balance. Tubers obtained from each plant were counted manually. Three tubers from each plant were selected randomly and diameter(mm) was determined with the vernier caliper. Roots were cut after harvesting the plant from the soil. The fresh roots of each plant were cleaned and mass was measured on field digital balance. Roots were dried and again weighover field digital balance.The harvest index was determined on dividing the tuber yield per plant with the total biomass.

Biometrical procedures

Data were analyzed in a completely randomized design with three replications under factorial arrangement on excel “addin” program by using DMR test. The breeding population (23) and intercropping (2) was considered as factors. The mean of traits showing significant variation due to accessions ($p \leq 0.05$) or significant accessions × intercropping ($p \leq 0.05$) were averaged over replications and discussed in the results and discussion. All the means of the accessions were shown in a bar graph with standard errors.

RESULTS

Analysis of variance showed significant variations due to the breeding population for all traits assessed in study. Moreover, treatment effects and interaction was also significant lines × intercropping regimes. The

significance of breeding population× intercropping regimes showed that there was a significant change in the ranking of breeding population across the intercropping regimes.
Impact of intercropping was obvious on all traits under study. Overall, breeding populations showed a decrease of 7% for chlorophyll contents, while leaf area, number of tubers per plant, tuber weight per plant, tuber diameter, shoot biomass, root biomass, total biomass, and harvest index showed an increase of 5%, 12%, 18%, 11%, 9%, 12%, 24%,and 6% increase due to intercropping regime respectively.
The mean values of traits have been shown in Figures 1-5. The SL14-32 showed the highest value of chlorophyll contents under intercropping regime while FD76-72 showed the highest chlorophyll contents under the non-intercropping regime (Fig. 1).
Populations showed a range of 56.33 to 151.33 and 33.06 to 140.33 under intercropping and non-intercropping regimes respectively for tuber weight plant^{-1}. Six populations showed an increase in tuber weight while four populations showed a decrease in tuber weight under intercropping regime when compared with non-inter cropping regime (Fig. 2). Populations such as FD-76-77 followed by SL-512, FD73-10 showed the highest tuber weight under intercropping regime while SL-15-15 showed the highest tuber weight under non-inter cropping regime (Fig. 3).
The range for shoot biomass was 13.50 to 56 under intercropping regime while it ranged from 12.19 to 57.67 under the non-intercropping regime. Six populations showed significant ($P \leq 0.05$) increase in shoot weight while five populations showed significant ($P \leq 0.05$) decrease in the intercropping regime when compared with the non-intercropping regime. FD74-30, FD63-1,and PRI-RED showed the highest value of shoot fresh weight under intercropping regime while SL-15-15 showed the highest shoot fresh biomass under the non-intercropping regime (Fig. 4).
The range among the breeding population was 80.83 to 206.50 and 34.57 to 203.83 in the intercropping and non-intercropping regime for total biomass. Twelve populations showed significant ($P \leq 0.05$) increase while only one showed a significant decrease in the total biomass under the intercropping regime. FD73-44, SL15-15 and FD76-67 showed the highest total biomass under intercropping regime while SL-15-15 showed the highest total biomass under the non-intercropping regime (Fig. 5).
The range of 2.00 to 8.67 and 1.28 to 7.00 was observed for number of tuber per plant among the breeding populations under intercropping and non-intercropping regime respectively showing that mean values increased under the intercropping regime. There were seven breeding populations which showed a significant increase in number of tuber per plant while two populations showed a significant decrease in the same regime. Breeding population SL-15-10 showed the highest number of tuber per plant in both regimes (Fig. 6).

Berseem weight

Berseem population cv. agaiti was grown in all the potato breeding population. The variation in the berseem biomass was due to differential competition with the potato populations (Fig 7). High biomass of berseem indicates less competitive potato population as it allowed the berseem to increase its biomass and growth. Analysis of variance showed significant berseem weight within potato populations, thus showing that there was the differential competitive ability of the potato populations. Berseem showed the highest biomass within three potato breeding populations i.e. FD73-49, FD60-2 and FD35-36. These populations may be considered less competitive which allowed higher berseem growth within their plot. Plant architecture such as low plant width, plant height,and small leaf area, canopy size contribute toward lower inter plant competition. However, these traits also contribute to lower yield traits. The identified less competitive populations were also lower tuber yielder as indicated from their tuber weight and over all plant biomass.

Correlation Analysis

Correlation analysis between various morphological and yield components was computed under both regimes (Table 1). Tuber weight per plant showed a significantcorrelation with all traits excluding chlorophyll contents, leaf area, number of tubers per plant and harvest index in the intercropping regime. Berseem weight had a negative relationship with tuber weight per plant. Tuber diameter had the highest positive relationship followed by the shoot dry weight and plant height with tuber weight per plant under the intercropping regime. In non-competitive regime, tuber weight showed a significant correlation with all traits except number of tubers per plant, root dry weight, shoot dry weight and chlorophyll contents (Table 2). The tuber weight was more strongly related with tuber diameter followed by leaf area and harvest index. The correlation analysis showed the importance of tuber diameter under both regimes.

DISCUSSION

A positive effect of intercropping observed over the tuber yield of the breeding populations. Intercrop potato with berseemled to 18% increased tuber yield. A subsequent increase in various components i.e.

number of tubers per plant (+12%), tuber diameter (+11%), fresh root weight (+12%) and total biomass (+24%). These increases in tuber yield were varied from 5.09% to 129.38% among the breeding population within intercropping. Intercrop potato with clover (Berseem) was beneficial due to its tender and non-competitive plant type. Clovers has the ability to fix and release free nitrogen in soil, which has a beneficial effect on biomass and yield of the potato tubers [14].The legume-cereal intercropping has been known to raise the fertility of the soil and also protect the land from soil erosion [14]. The beneficial impact of intercropping in legumes such as red clover has been identified. It was identified that red clover can supply 36 kg of nitrogen for subsequent corn crop [5]. The intercropping conserves natural resources and protects from soil erosion, surface water runoff, and also suppressed weed and pathogens [4,5]. The potato and grass-clover strip intercropping resulted in the reduction of 9-20% on blight severity of Potatoes. The crop diversity within field acts as a buffer against the spread of inoculum within the field. The impact of potato and maize strip intercropping has been studied in a number of studies [1, 2]. Maize and Potato crop was grown in various ratios. For instance, 3:1 (Potato: Maize) or 1:1 (Potato: Maize) [2]. The beneficial impact of intercropping was noted in these studies. There was an increase in the leaf area index and plant density and also a significant increase in the potato tuber yield as result of intercropping [1]. Moreover, there was also some increase in height of potato plants, biomass of plants and tuber weight due to the intercropping of maize and potato [1]. The benefit of intercropping was also seen with a legume. The yield advantage of wheat-soybean co-cultivation was 28-30% [12].

Table 1. Correlation analysis between various morphological traits related to yield and its components under berseem intercropping regime i.e. number of tiller per plant (NTP), tuber weight (TW), root fresh weight (RFW), root dry weight (RDW), shoot fresh weight (SFW), tuber diameter (TD), harvest index (HI), berseem weight (BW), plant height (PH) and chlorophyll contents (CC)

Traits	NTP	TW	RFW	RDW	SFW	SDW	TD	HI	BW	PH	CC
TW	0.37^{NS}										
RFW	0.46*	0.56**									
RDW	0.46*	0.53**	0.92**								
SFW	0.29^{NS}	0.57**	0.63**	0.68**							
SDW	0.42*	0.65**	0.70**	0.75**	0.96**						
TD	-0.11^{NS}	0.65**	0.32^{NS}	0.21^{NS}	0.27^{NS}	0.31^{NS}					
HI	0.05^{NS}	0.15^{NS}	-0.23^{NS}	-0.38^{NS}	-0.59*	-0.48*	0.42*				
BW	-0.68**	-0.76**	-0.53*	-0.56**	-0.40^{NS}	-0.50*	-0.31^{NS}	-0.15^{NS}			
PH	0.27^{NS}	0.58**	0.56**	0.61**	0.75**	0.83**	0.25^{NS}	-0.28^{NS}	-0.28^{NS}		
CC	-0.03^{NS}	0.06^{NS}	0.09^{NS}	-0.03 ^{NS}	0.28^{NS}	0.32^{NS}	0.20^{NS}	0.00^{NS}	0.00^{NS}	0.28^{NS}	
LA	-0.18^{NS}	0.20^{NS}	0.11^{NS}	-0.04^{NS}	0.01^{NS}	-0.02^{NS}	0.51*	0.34^{NS}	0.34^{NS}	0.04^{NS}	0.08^{NS}

Where** was highly significant at ($p \leq 0.01$), * significant at ($p \leq 0.05$)

Table 2. Correlation analysis between various morphological traits related to yield and its components under berseem intercropping regime i.e. number of tiller per plant (NTP), tuber weight (TW), root fresh weight (RFW), root dry weight (RDW), shoot fresh weight (SFW), tuber diameter (TD), harvest index (HI), plant height (PH) and chlorophyll contents (CC)

Traits	NTP	TW	RFW	RDW	SFW	SDW	TD	HI	PH	CC
TW	0.09^{NS}									
RFW	0.30^{NS}	0.48*								
RDW	0.45*	0.27^{NS}	0.89**							
SFW	0.34^{NS}	0.45*	0.57**	0.64**						
SDW	0.42*	0.37^{NS}	0.61**	0.68**	0.93**					
TD	0.02^{NS}	0.78**	0.42*	0.24^{NS}	0.29^{NS}	0.26^{NS}				
HI	0.11^{NS}	0.62**	0.23^{NS}	0.05^{NS}	-0.17	-0.11^{NS}	0.75**			
PH	0.26^{NS}	0.48**	0.23^{NS}	0.30^{NS}	0.67**	0.68**	0.38^{NS}	0.06^{NS}		
CC	0.09^{NS}	-0.28^{NS}	0.06^{NS}	0.01^{NS}	0.22^{NS}	0.23^{NS}	-0.42*	-0.50*	0.04^{NS}	
LA	0.30^{NS}	0.69**	0.64**	0.55**	0.63**	0.61**	0.72**	0.42**	0.56**	-0.29^{NS}

Where** was highly significant at ($p \leq 0.01$), * significant at ($p \leq 0.05$)

The results showed that there was significant variation among the breeding populations for their response to the intercropping. However, the magnitude of genetic variation as indicated by the genotypic coefficient of variation in various plant traits was low to medium (Table 1), which showed that most of the breeding populations have an average response to the intercropping. This is in contrast to the previous which showed some genotypic variation within potato germplasm [15, 7, 8]. The reduction in genetic variability was due to the selection on the basis of a similar criterion for development of high yielding cultivars, sharing common parentage in lineage and development of cultivar for single environment i.e. high input environment [18-20].

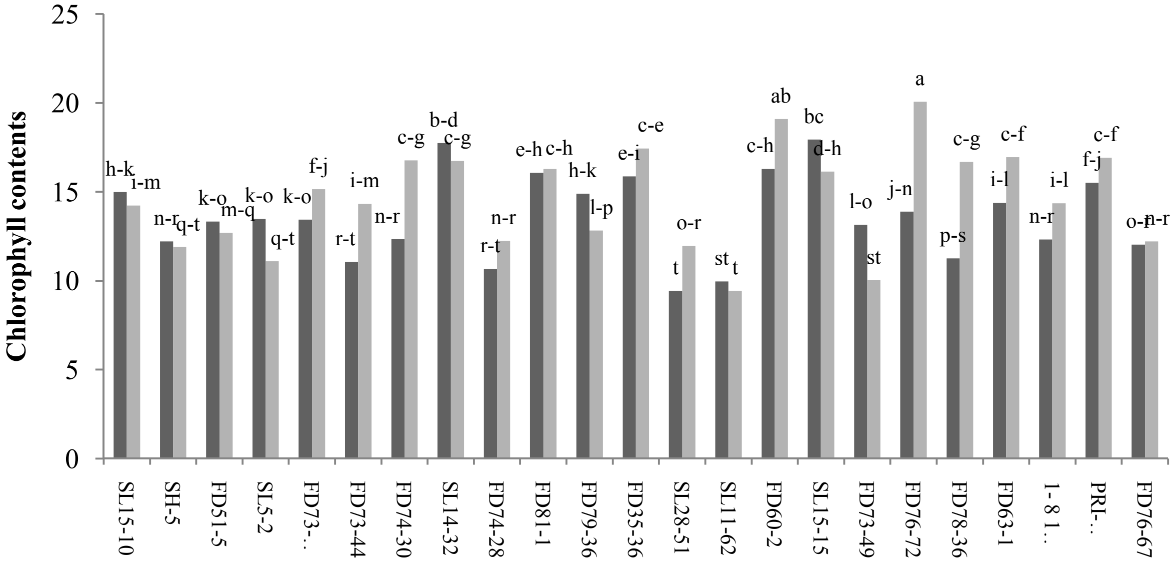

Fig. 1. Mean values of 23 breeding populations for chlorophyll contents of potato (*Solanum tuberosum* L.) under intercropping (dark bar) and non-inter cropping (light gray bar) regime. Bars showing similar letters were statistically similar ($p \geq 0.05$) as per DMR test.

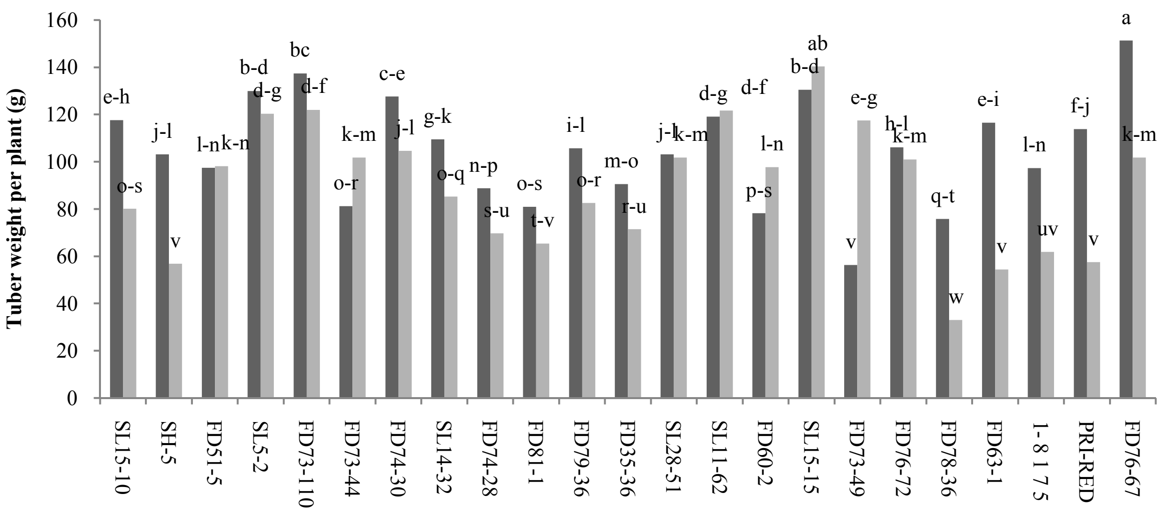

Fig. 2. Mean values of 23 breeding populations for tubers weight per plant of potato (*Solanum tuberosum* L.) under intercropping (grey bar) and non-inter cropping (light gray bar) regimes. Bars showing similar letters were statistically similar ($P \geq 0.05$) as per DMR test.

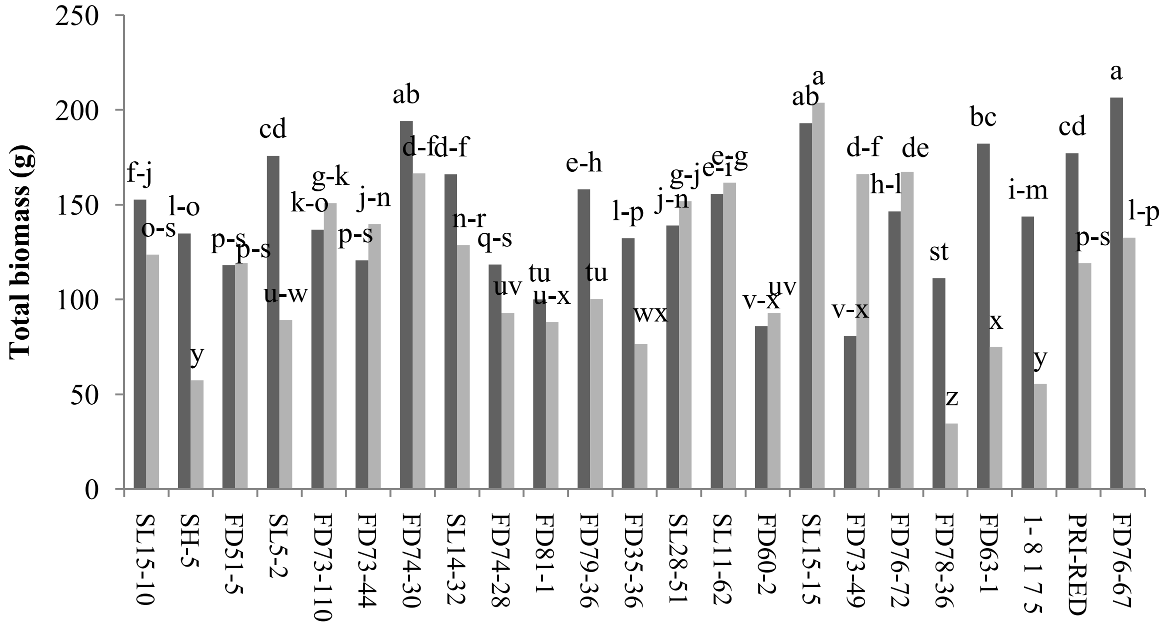

Fig 3. Mean values of 23 breeding populations for total fresh weight per plant of potato (*Solanum tuberosum* L.) under intercropping (grey bar) and non-inter cropping (light gray bar) regimes. Bars showing similar letters were statistically similar (P ≥ 0.05) as per DMR test.

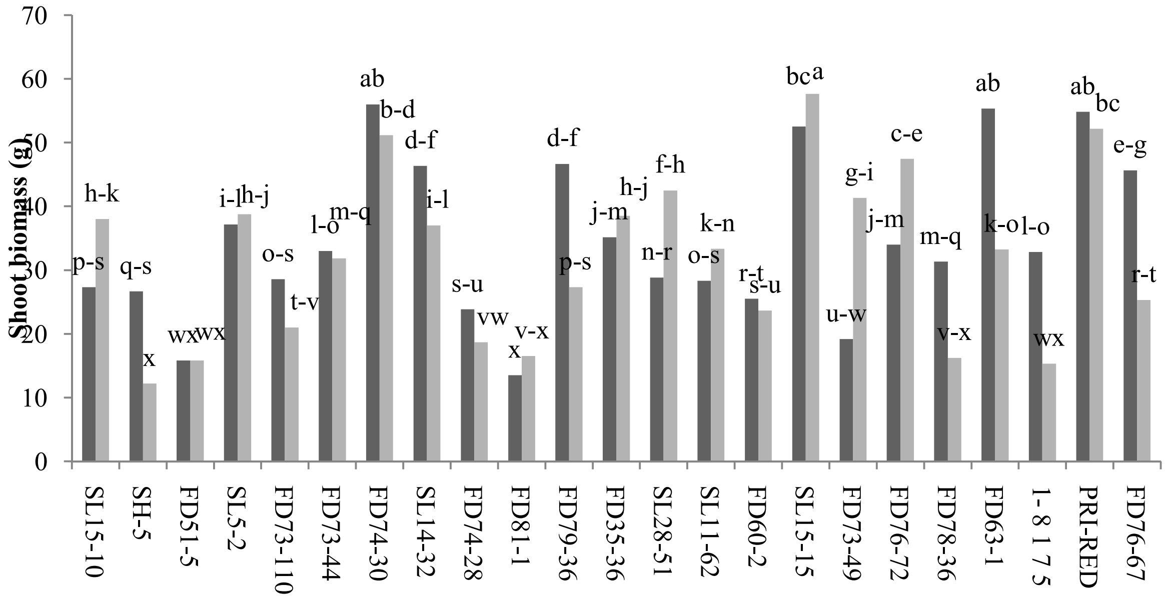

Fig. 4. Mean values of 23 breeding populations for shoot biomass per plant of potato (*Solanum tuberosum* L.) under intercropping (grey bar) and non-inter cropping (light gray bar) regimes. Bars showing similar letters were statistically similar ($p \geq 0.05$) as per DMR test.

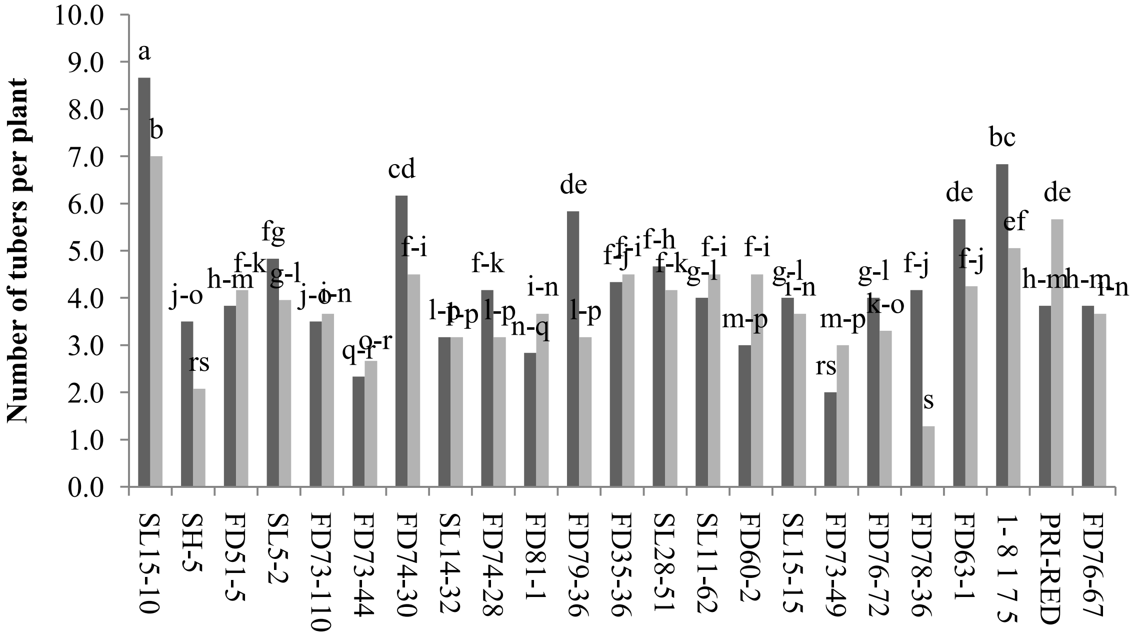

Fig. 5. Mean values of 23 breeding populations for number of tubers per plant of potato (*Solanum tuberosum* L.) under intercropping (grey bar) and non-inter cropping (light gray bar) regimes. Bars showing similar letters were statistically similar ($p \geq 0.05$) as per DMR test.

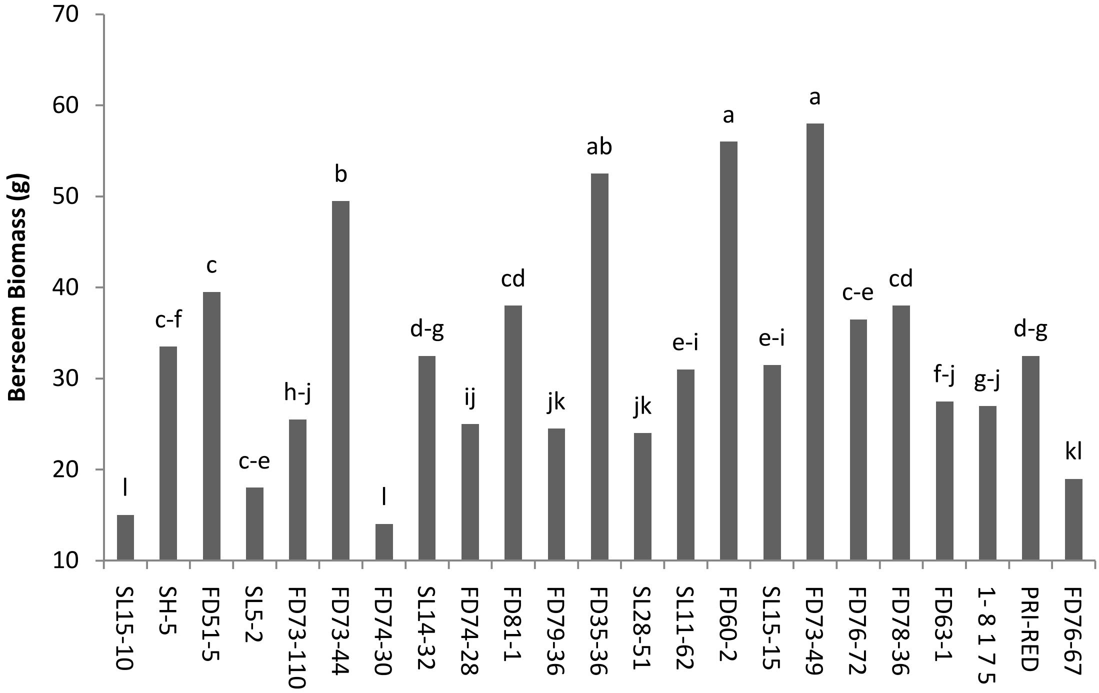

Fig 6. Biomass of berseem (*Trifolium alexandrinum*L.) population cv. agaiti intercropped with 23 advanced lines of potato (*Solanum tuberosum* L.). Bars showing similar letters were statistically similar ($p \geq 0.05$) as per DMR test.

Heritability associated with traits was low for the trait of interest such as for tuber weight per plant, total plant biomass over contrasting intercropping regime. Thus showing that selection on the basis of these traits was not possible for the range of environment. On the other hand, a trait with moderate to high heritability may provide good selection responses under multiple regimes. The traits with high heritability and positive relationship with tuber yield were shown to be good selection criterion [7]. The traits such as harvest index have shown moderate heritability and showed a positive relationship with tuber weight under the non-intercropping regime (Table 1). Thus harvest index may be exploited to be utilized as selection criterion under the non-intercropping regime. Tuber diameter had low heritability but was positively related with tuber weight under both regimes. However, tuber diameter may be selected through the leaf area which showed a positive relationship with tuber diameter under both regimes [13]. The positive relationship between the leaf area and potato diameter was due to the higher interception of light which was translocated to growing tubers [6, 22]. Heritability estimates were moderate over both regimes. Moreover, it showed a positive relationship with tuber weight under the non-intercropping regime. The leaf area may be determined earlier in the crop growth cycle and thus may be used to discriminate genotypes well before the crop harvest [9]. However, there was low genetic variation within the leaf area which could be augmented by the introduction or exchange of diverse germplasm from various potato collections centers.

CONCLUSION

The results of the present study showed that intercropping may lead to the increase in tuber yield and its components such as tuber weight, harvest index, total biomass. The tuber yield had low heritability thus selection for the tuber yield per se would result in low selection gains. Tuber diameter had the highest correlation with tuber yield in both regimes. Therefore, tuber diameter trait may be improved to increase tuber yield. Leaf area may be used to improve tuber diameter due to its positive correlation with tuber diameter and high value of heritability. The trait could also be used to discriminate the genotypes before the plants reach maturity.

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Author's Contribution

IUH perceived the idea, planned experiment and provided technical assistance for writing the manuscript. ZI conducted an experiment, collected data and prepared draft of the manuscript. SR helped in data analysis, write up and proof reading. EA, WR and SA helped in proof reading and improving the language of the manuscript. All authors read and approved the final manuscript.

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