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73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor, Kenyatta Avenue, Nairobi, Kenya
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Division of Crop Improvement  
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Global Theme on crop improvement International Crops Research Institute for the Semi Arid Tropics (ICRISAT) Patancheru - 502 324 Andhra Pradesh India.
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Effect of *Alternaria* sp on seed germination in rapeseed, and its control with seed treatment

Tufail Ahmad Soomro1*, Muhammad Ismail1, Safdar Ali Anwar2, Raza Muhammad Memon1 and Zubair Ahmad Nizamani3

1Department of Plant Pathology, Sindh Agriculture University Tando Jam, Pakistan.
2Nuclear Institute of Agriculture Tando Jam, Pakistan.
3Institute of Agricultural Sciences, PU Lahore, Pakistan.

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The role of *Alternaria* sp on seed vigor of rapeseed, *Brassica napus*, was investigated. Seed samples were collected from rapeseed growing regions of Sindh province. The samples were processed for fungal recovery using blotter paper and agar plate methods. Both methods produced a number of parasitic and saprophytic fungi. Among the recovered fungi, *Alternaria* sp was predominant with 16% average infection. Similarly, effect of seed treatment with Tospin M. was examined in this experiment. It improved seed health significantly over inoculated seeds. The treated seeds showed greater germination (16.15%) with 83.69% more healthy seedling in comparison with inoculated seeds. Root and shoot systems were significantly improved in seedlings from treated seed compared to those from inoculated seeds. The results of this study suggest grading seed samples to reduce seed impurities and seed treatment (particularly with Tospin M) to eliminate seed borne pathogen, especially *Alternaria* from rapeseed to enhance production by the growers.

**Key words:** Seed health, seed borne fungi, *Alternaria*, seed treatment.

**INTRODUCTION**

Seed health is a key factor in sustainable crop production. Disease free plants ensure a healthy crop stand in the field. This provides better outputs at farm level. However, seed borne pathogens are known to affect seed health and its vigor. A number of crop diseases are disseminated to distinct areas through infected seeds (Kandhare, 2014). As a result, new diseases are easily established in those environments. Seed contamination with such pathogens occurs in many ways like direct infection on the field and improper storage conditions. High relative humidity, suitable temperature and higher moisture content enhance pests and diseases establishment in seeds. Infestation by these fungi has been observed in all parts of the seeds as it harms seed tissues externally or internally causing seed rot, necrosis and seedling diseases (Anwar et al., 1994; Al Kassim 1996; Rai et al., 2015).

Pre- and post-emergence seedling diseases contribute significantly to poor crop stands. Majority of plant pathogens that attack rapeseed are seed borne in nature.

*Corresponding author. E-mail: tufailahmed480@yahoo.com.*

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Particularly, *Alternaria brassicola*, *Alternaria alternate*, *Curvularia lunata* and *Fusarium* spp. are of great concern. *A. brassicicola* is the most common pathogen of most crops belonging to the same group as rapeseed along with *A. alternata* (Gupta and Chaudhary, 1994). Black spot in rapeseed due to *A. brassicicola* is a seed borne disease. *Alternaria* is known to produce a number of toxins which help it to overcome the host resistance. These toxins cause tissue necrosis with cell-wall degrading enzymes (Ahmad and Sinha, 2002; Cho et al., 2016; Zaheer et al., 2015).

Therefore, early defoliation, flower-bud abortion, and premature ripening due to severe infection of these diseases results in substantial yield losses (Seidle et al., 1995; Kumar et al., 2014). Under such circumstances, 20 to 30% losses in rapeseed yields have been observed in Canada (Mc Donald, 1959; KL et al., 1990). Apart from this effect, a number of seed-borne fungi including *Aspergillus flavus*, *A. ochraceus*, *Rhizopus*, *Mucor* and *Fusarium* spp. produce mycotoxins.

Consequently, these toxins not only reduce germination but also induce biochemical changes in seeds (Kandhare, 2015; Farid et al., 2017a; b). In oilseed crops, the presence of these fungi in seed deteriorates oil and sugar contents, and their quality. Oil seed crops are very important for edible oil production worldwide. But these have not gained much importance in Pakistan. Currently, due to increased demand of good quality edible oils, special focus is being given to exploit the potential of local and exotic rapeseed germplasm. Significant achievements at national level have been made in canola types with better oil content than the indigenous material. This has increased the demand for good quality and disease-free seed of these genotypes at farm level. The present investigation was carried out on the association of *Alternaria*, and other seed mycoflora with rapeseed.

**MATERIALS AND METHODS**

**Collection of seed samples**

Seed samples of rapeseed were collected from grain markets, and farmers’ lots from rapeseed growing pockets of Sindh. The samples inspected were processed for the association of seed-borne fungi followed (ISTA, 2005) by visual/dry inspection of seeds, standard blotter paper and agar plate methods and seedling assay.

**Visual/dry inspection of rapeseed seeds**

1 kg seed of each sample was examined visually for the presence of impurities, broken seeds or any fruiting structure. Contaminated seeds were observed under stereomicroscope for the confirmation of these impurities.

**Standard blotter paper method**

Seeds of each sample were placed aseptically on three layers of water soaked blotter paper. The experiment was conducted under completely randomized design (CRD) with five replications. Five seeds were placed in each Petri plate (9 cm), and three petri plate of each sample per replication were used. The plates were incubated at 25±2°C for 7 days under fluorescent light (ISTA, 1993). After incubation, seeds were examined under stereoscopic microscope. The initial growth of each fungus was purified on potato dextrose agar (PDA) medium. Percentage infection for each fungus was calculated by counting infected seed out of the total plated seeds.

**Agar plate method**

Potato dextrose agar medium was used for fungal recovery from rapeseed seeds. Media and glassware were sterilized at 121°C, and 15 lps psi for 15 min. About 15 ml of sterilized PDA medium was poured in each Petri dish (9 cm) under aseptic conditions. 5 seeds of each sample were placed directly in each Petri dish containing nutrient media under aseptic conditions. The Petri plates were incubated at 25±2°C for 7 days. The experiment was conducted under CRD with five replications. Each fungus was identified on the basis of spore/ conidia formation under a compound microscope according to Booth (1971), Ellis (1971), Barnett and Hunter (2003), Subramanian (1971), Larone (2002) and Schell (2003) in addition to the use of various keys and pigtograms.

**Seed inoculation**

Inoculum of *Alternaria* was prepared for pathogenicity test. Seeds of the test cultivars were dipped in the conidial suspension (10⁶ conidia ml⁻¹) of each fungus. These seeds were sown in earthen pots containing sterilized soil. One hundred seeds of each sample were sown in earthen pots with three replications using completely randomized design. Untreated seeds sown in earthen pots served as control. Isolations were also made from the seeds that failed to germinate, and infected seedlings to re-isolate the fungus.

**Effect of fungicides dressing on seed-borne mycoflora of rapeseed seeds**

Composite seed samples of each rapeseed sample were treated with thiophanate methyl (active ingredient Topsin-M) at 2.5g/ Kg seed. The treated seeds were sown in earthen pots containing sterilized soil under greenhouse condition. The seeds without fungicides treatment served as control. Germination in treated and non treated seeds was recorded after 7 days. Similarly, the germination % rotted seeds, abnormal seedlings and root shoot length were calculated.

**RESULTS**

**Association of various seed borne fungi with rapeseed seeds**

The presence of seed impurities such as fruiting bodies, dead and dry seeds were examined visually using magnifying glasses for estimation. All the samples showed the presence of these impurities. However, the overall proportion of seed debris was significantly higher than the broken seeds. Straw, dust particles, and seeds of other crops were the main debris in all samples. These were less in sample numbers 17 and 18 while
their percentage was higher in samples 1, 7, 13 and 20. Broken seeds and mummies were observed in all samples. These may result during postharvest or some other physical damages (Bux et al., 2013). These are not only the cause of disease spread but also provide a good shelter for overwintering and survival of pathogens (Figure 1).

Blotter paper and agar plate methods were used for the recovery of Alternaria from seed samples. The results revealed that its colonization was significantly higher in blotter paper (Figure 2). In order to find and examine the maximum fungal population, seed blotter paper method was seen to be very effective (Elwakil and Ghoneem, 1999; Walcott, 2003). This provided excellent conditions for mycelial growth and sporulation of several fungi (Neergaard, 1979). Morphological characteristics were identified according to Larone (2002) and Schell (2003). Apart from Alternaria, a number of other fungi were also observed. The present results are also in conformity with Saleh et al. (2003), who have reported the prevalence of various seed borne fungi in rapeseed. Alternaria sp is responsible for leaf spot disease in oil seeds and also for loss of seed viability (Malaker et al., 2008).

**Effect of culture filtrate of Alternaria and fungicide dressing on seed health of rapeseed**

The results of this study revealed significant differences in seed germination, number of abnormal seedling and root shoot length in inoculated and treated seeds. The seedlings of the treated seeds (Table 2) were healthy.
with proper root and shoot. No abnormal symptoms were observed. However, in inoculated seeds (Table 1), less seed germination and more abnormal seedlings with reduced root and shoot system were observed. Seed mycoflora is reported to reduce seed germination thus causing pre- and post- emergence seedling death. Shrestha et al. (2000) in a pathogenicity study observed symptoms of Alternaria in rapeseed seedlings. Similarly, the infection deteriorates seed health and reduces germination (Ismail et al., 2004; Anwar et al., 1994; Elwakil and Ghoneem 1999). Nowadays, chemical seed treatment is very common worldwide due to its wide spectrum ability to control plant diseases (Nameth, 1998). In our farming system, this could not get much importance, there is need to educate farmers about seed treatment.

DISCUSSION

The present work revealed the occurrence of various impurities in all collected samples. Among the twenty rapeseed samples, only a few showed fewer impurities (Figure 1). Presence of such impurities affects seed health and marketing. Among the methods of fungal detection from rapeseed blotter paper method, agar plate was found to be very effective. Alternaria was the most predominant fungus with an average infection of 16% in all samples among the isolated fungi.

The location of Alternaria in seed is very important. It mostly resides in seed coat and sporulates in the hilum Region (Shrestha et al., 2003; Walcott 2003). Seed infection transmits Alternaria to seedlings. Plant pathogenic Alternaria sp produces host specific toxins, and use secondary metabolites in disease initiation, apart from toxins, certain lipase and cell wall-degrading enzymes contribute significantly in its pathogenesis (Chao, 2016; Rathod, 2012).

Seed borne fungi are responsible for mycotoxin production in seeds, and induce biochemical changes resulting in damaged seed contents (Swami and Alane, 2013). As a result, quality of oil contents in seed is affected (Wani et al., 2012).

The role of Alternaria in seed germination was also investigated in this study. Reduced seed germination was observed in all samples. The important symptom found were seed rot, lesion on seedling and reduced root shoot system. Successful re-isolations were made from infected seedlings and rotted seeds. These results are in conformity with Shrestha et al. (2005) who observed that lesions on cotyledonary and first true leaves were due to seed-borne inoculum. Adverse effects of mycotoxins which inhibited the growth of seedlings have been reported by Howlett (2006). Impact of fungicides treatment on fungal population was also investigated in this study.

Significant difference was noticed in seed germination

<table>
<thead>
<tr>
<th>Seed sample</th>
<th>% Germination</th>
<th>Rotten seeds</th>
<th>Abnormal seedlings</th>
<th>Root length(cm)</th>
<th>Shoot length(cm)</th>
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Table 1. Effect of culture filtrate of Alternaria on seed health of rapeseed.
Table 2. Effect of fungicide dressing on seed health of Rapeseed.

<table>
<thead>
<tr>
<th>Seed samples</th>
<th>% germination</th>
<th>Rotted seeds</th>
<th>Abnormal seedlings</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
</tr>
</thead>
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<tr>
<td>6</td>
<td>91.67 BCDEF</td>
<td>7.67 ABCD</td>
<td>0.67 E</td>
<td>7.67 AB</td>
<td>11.00 BCDE</td>
</tr>
<tr>
<td>7</td>
<td>91.67 BCDEF</td>
<td>8.00 ABC</td>
<td>1.00 D</td>
<td>7.33 AB</td>
<td>9.67 E</td>
</tr>
<tr>
<td>8</td>
<td>92.00 BCDE</td>
<td>6.00 BCDE</td>
<td>2.00 C</td>
<td>7.67 AB</td>
<td>11.67 ABCDE</td>
</tr>
<tr>
<td>9</td>
<td>92.33 ABCD</td>
<td>6.33 BCDE</td>
<td>3.00 B</td>
<td>7.67 AB</td>
<td>12.33 ABC</td>
</tr>
<tr>
<td>10</td>
<td>93.333 ABC</td>
<td>6.00 BCDE</td>
<td>1.00 D</td>
<td>7.33 AB</td>
<td>13.00 AB</td>
</tr>
<tr>
<td>11</td>
<td>88.67 H</td>
<td>7.00 ABCD</td>
<td>3.00 B</td>
<td>6.67 B</td>
<td>11.33 ABCDE</td>
</tr>
<tr>
<td>12</td>
<td>89.00 GH</td>
<td>7.67 ABCD</td>
<td>3.00 B</td>
<td>8.00 AB</td>
<td>12.33 ABC</td>
</tr>
<tr>
<td>13</td>
<td>90.00 EFGH</td>
<td>5.33 DE</td>
<td>4.00 A</td>
<td>7.33 AB</td>
<td>10.67 CDE</td>
</tr>
<tr>
<td>14</td>
<td>92.00 BCDE</td>
<td>5.67 CDE</td>
<td>1.00 D</td>
<td>6.67 B</td>
<td>10.33 CDE</td>
</tr>
<tr>
<td>15</td>
<td>90.67 DEFGH</td>
<td>6.33 BCDE</td>
<td>3.00 B</td>
<td>7.67 AB</td>
<td>10.33 CDE</td>
</tr>
<tr>
<td>16</td>
<td>93.67 AB</td>
<td>6.33 BCDE</td>
<td>1.00 D</td>
<td>8.67 A</td>
<td>10.67 CDE</td>
</tr>
<tr>
<td>17</td>
<td>93.667 AB</td>
<td>6.33 BCDE</td>
<td>1.00 D</td>
<td>8.00 AB</td>
<td>10.67 CDE</td>
</tr>
<tr>
<td>18</td>
<td>93.333 ABC</td>
<td>7.00 ABCD</td>
<td>2.00 C</td>
<td>8.00 AB</td>
<td>12.00 ABCD</td>
</tr>
<tr>
<td>19</td>
<td>91.33 CDEF</td>
<td>7.00 ABCD</td>
<td>2.00 C</td>
<td>7.33 AB</td>
<td>12.00 BCDE</td>
</tr>
<tr>
<td>20</td>
<td>89.67 FGH</td>
<td>7.67 ABCD</td>
<td>2.00 C</td>
<td>7.00 AB</td>
<td>13.33 A</td>
</tr>
</tbody>
</table>

LSD 2.2746 2.5207 0.2130 1.7696 2.1934

Table 3. Comparison of seed treatment and seed inoculation.

<table>
<thead>
<tr>
<th>Seed health parameter</th>
<th>Treated</th>
<th>Inoculated</th>
<th>% improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination %</td>
<td>91.45</td>
<td>76.35</td>
<td>16.15</td>
</tr>
<tr>
<td>Rotted seed</td>
<td>6.89</td>
<td>8.4</td>
<td>17.97</td>
</tr>
<tr>
<td>Abnormal seedlings</td>
<td>1.88</td>
<td>11.53</td>
<td>83.69</td>
</tr>
<tr>
<td>Root length</td>
<td>7.48</td>
<td>4.26</td>
<td>43.04</td>
</tr>
<tr>
<td>Shoot length</td>
<td>11.32</td>
<td>4.19</td>
<td>62.98</td>
</tr>
</tbody>
</table>

and seedling health of treated and untreated seed (Table 3). The seeds treated with Topsin M showed maximum germination with healthy seedlings. These results are in accordance with Bhuiyan et al. (2013) and Sharma et al., (2015) who have observed better seed germination in fungicide treated seed. Sinha and Prasad (1981) reported less seed germination as a result of Alternaria infection. In order to reduce such infection, improving seed treatment is an effective method (Anjorin and Mohammad, 2014; Naher et al., 2016).

This does not only reduce seed borne infections but also protects the emerging seedlings from fungal infection (Kamal and Verma, 1987). As a result, pre- and post-emergence seedling mortality are reduced. According to Chilkuri and Giri (2014), seedling blight was due to seed borne fungi infection. The present work highlights the association between Alternaria and rapeseed. From the aforementioned, it can be concluded that blotter paper is an effective method in detecting seed borne infection such as Alternaria.

Seed borne fungi reduces seed germination (as is evident from the present results) therefore, seed treatment is recommended. It is also suggested that awareness must be created among farmers about seed treatment so that they can protect their crops from these pathogens. Foliar application of fungicides is an important component of disease management in plants. Therefore, judicious use of these fungicides especially, Topsin M, is recommended to overcome Alternaria diseases in rapeseed crop.
CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES


Shrestha SK, Mathur SB, Munk L (2000). Alternaria brassicaceae in seeds of rapeseed and mustard, its location in seeds, transmission from seeds to seedlings and control. Seed Science and Technology (Switzerland) 28(1):75-84.


Growth and yield response of two groundnut cultivars to row pattern in the forest-Savannah Transition Zone of Ghana

Essilfie M. E. 1*, Dapaah K. H. 1, Essilfie K. J. 2, Asmah F. B. 1 and Donkor F. 3

1Department of Crop and Soil Sciences Education, Faculty of Agriculture Education, University of Education, Winneba, P. O. Box 40, Mampong-Ashanti, Ghana.
2Mt Mary College of Education, P. O. Box 19 Somanya, Ghana.
3Department of Agriculture Economics and Extension, Faculty of Agriculture Education, University of Education, Winneba. P. O. Box 40, Mampong-Ashanti, Ghana.

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Two field trials (2017 and 2018) were conducted at the research field of the University of Education, Winneba, Mampong Campus from May to August to determine the growth and yield response of groundnut to row pattern. The experimental design was a 2 x 4 factorial arranged in a randomized complete block design (RCBD) with three replications. The factors studied included: (A) Cultivar [(i) Yenyawoso and (ii) Adepa] and (B) Row pattern [(i) 50 cm x 10 cm, (ii) 60 cm x 10 cm single row, (iii) 50 cm x 20 cm x 20 cm (iv) 60 cm x 20 cm x 20 cm twin row]. The result revealed that Adepa produced taller plants, higher number of branches at 86 DAP, taller plants, 100 - seed weight and number of pods/plant than Yenyawoso. The 50 cm x 20 cm x 20 cm twin row pattern produced higher number of branches, taller plants, number of plants harvested and pod yield than other row pattern. The 60 cm x 20 cm x 20 cm twin row pattern produced higher 100 - seed weight and higher number of pods/plant than 50 cm x 10 cm and 60 cm x 10 cm single row pattern. Interaction effect between variety x row pattern was significant with number of branches at 58 and 86 DAP in 2018 cropping season. In conclusion groundnut farmers are to grow Adepa cultivar of groundnut using 50 cm x 20 cm x 20 cm twin row pattern for high yield and vegetative biomass. For heavy seeds farmers should grow Adepa using 60 cm x 20 cm x 20 cm twin row pattern.

Key words: Groundnut, Adepa, Yenyawoso, single row pattern, twin row pattern.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is one of the world most popular crops grown in tropical and sub-tropical regions. The crop belongs to the family Fabaceae. It originated from South American, but it is now widely...
cultivated throughout the tropical, sub-tropical and temperate countries, and in Africa, Asia, North and South America. Due to its high protein, oil, fatty acid, carbohydrates, vitamins and minerals content, the crop has high commercial and nutritional values. Groundnut seeds are a rich source of oil (35-56%), protein (25-30%), carbohydrate (9.5-19%) and minerals (Gulluoglu et al., 2016a; Gulluoglu et al., 2016c). In Ghana, the paste obtained after the oil has been extracted can be moulded into different shapes and fried as 'krukul'. The crop is intercropped with other cereal crops such as pearl millet, maize, sorghum and cassava. Its cake is used as feed and haulms provide quality fodder (Martey et al., 2015).

Groundnut production in Africa covers 31.3% land area and 18.6% production. Ghana is one of the top six countries producing groundnut in Africa (FAO, 2008). Groundnut total production in Ghana range from 209,000 tons in 2000 to 530,887 tons in 2010 and it is mostly produced by smallholder farmers (Angelucci and Bazzucchi, 2013). It is estimated that more than 70% of farmers in the three northern regions of Ghana grow groundnuts and together account for over 85% of the national output. Groundnut is an important legume crop grown and marketed by farmers in the study area. The crop provides substantial income which has helped to improve their livelihoods over the years. Most of the grains are transported to large market centres where they are sold and used for food and oil preparations. However, production has been on subsistence level with low crop yield. This is due to inappropriate use of agronomic factors such as row planting pattern. In addition farmers have been using local groundnut varieties for cultivation which usually give low yield. Single row planting pattern has been a traditional cultivation method used by groundnut farmers in the forest-savannah transitional agro-ecological zone of Ghana. For improved groundnut varieties it is important to accommodate the most appropriate row planting pattern and number of plants per unit area to obtain better yield (Gulluoglu et al., 2016b).

Understanding the proper planting pattern is very important to increase crop yield (Knezevirc et al., 2003). A particular planting pattern for a specific leguminous crop may provide an optimum space to maximize vegetative parts which will receive higher solar energy and results in maximum yield. Adjusting row planting pattern is one of the important agronomic practices for increasing yield of row crop and reducing competition in environmental and soil resources. The response of groundnut to single-row and twin-row pattern has been investigated by many researchers. Gulluoglu et al. (2016) reported that twin row pattern increased yield (4906 kg ha⁻¹) from 80 cm x 25 cm x 80 cm x 30 cm (63.2 plants m⁻²) than single row pattern with yield (35.7 plants m⁻²). The yield increase was however, 24.4% in twin row pattern than conventional single row pattern (standard). There is however, limited research conducted and little information available to compare the performance of newly released groundnut cultivars in terms of growth and yield as influenced by single and twin row pattern in the study area. The study therefore seeks to determine the effect of row pattern on growth, yield and yield components of two cultivars of groundnut in the forest-savannah transition zone of Ghana.

MATERIALS AND METHODS

Description of study area

Two field experiments were carried out at College of Agriculture Education of the University of Education, Winneba, Asante Mampong campus during 2017 and 2018 cropping seasons. The experimental site is gently inclined and is well drained. The climatic conditions at the experimental sites for 2017 and 2018 cropping seasons is presented in Table 1. The climatic conditions during the field research periods show that differences in environmental factors (rainfall, temperature and relative humidity) were shown in both cropping seasons. The overall monthly rainfall during the 2017 cropping season was 512.4 mm and it occurred from May to August, 2017 with the peak in May and June (Meteorological Department- Mampong-Aschanti, 2017). The average monthly temperature of the experimental site for the 2017 cropping season was between 21.7 to 32.4°C, with the highest daily of 32.4°C occurring in May. The mean monthly relative humidity ranged from 63% to 97% with the highest occurring between June and July. In the 2018 cropping season, the overall monthly rainfall was 568.0 mm and it occurred from May to August with the peak in May and June (Meteorological Department- Mampong- Aschanti, 2018). The average monthly temperature of the experimental site for the 2018 cropping season was between 21.2 to 31.1°C, with the highest daily of 31.1°C occurring in May. The mean monthly relative humidity ranged from 65% to 92% with the highest occurring between May and June.

The soil at the experimental site has been categorized as Chronic Luvisol and locally as the Bediesi series with a pH range of 4.0-6.5 suitable for root, cereal, vegetable and legume crops production (Asiamah, 1988; FAO/UNESCO, 1988) legend.

Experimental design and planting

The experimental design was a 2x4 factorial arranged in a Randomized Complete Block Design (RCBD) with three replications. The factors studied included: (A) Variety (Yenyawoso and Adepa) and (B) Row pattern and spacing (i) 50 cm x 10 cm single, (ii) 60 cm x 10 cm single row, (50 cm x 20 cm) x 20 cm twin row and (iv) (60 cm x 20 cm) x 20 cm twin row. The total field size of 28.8 m x 13 m (374.4 m²) was demarcated, cleared, lined and pegged and ridges prepared. Each experimental plot measured 2 m x 2 m, 2.4 m x 2 m, 2.8 m x 2 m and 3.2 m x 2 m, respectively based on the respective treatment. Each experimental plot had 120 plants based on row planting spacing and pattern. A space of 2 m was left between blocks with 1 m interval between plots. Two cultivars Yenyawoso and Adepa seeds obtained from Crops Research Institute (CSIR) in Kumasi, Ghana were used as a plant material in the study. Both cultivars have a semi-erect growth form with high oil content in the seed, high yield capacity and a growing period of between 60 to 115 days. Three seeds of Yenyawoso and Adepa were planted per hill at a depth of 3-4 cm according to planting spacing and row patterns. Seedlings were thinned to 1 plant per hill 8 days after emergence. Each treatment plot had 4 rows on single row pattern with thirty plants on each row and eight rows on twin row pattern with fifteen plants on each row.
### Table 1. Climatic data for 2017 and 2018 experimental periods.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total monthly rainfall (mm)</th>
<th>Mean monthly relative humidity (%) (Hours GMT)</th>
<th>Mean monthly temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
<td>06.00</td>
</tr>
<tr>
<td>May</td>
<td>161.2</td>
<td>184.6</td>
<td>95</td>
</tr>
<tr>
<td>June</td>
<td>175.0</td>
<td>185.5</td>
<td>97</td>
</tr>
<tr>
<td>July</td>
<td>139.3</td>
<td>157.2</td>
<td>97</td>
</tr>
<tr>
<td>August</td>
<td>51.8</td>
<td>40.7</td>
<td>96</td>
</tr>
<tr>
<td>Total</td>
<td>512.4</td>
<td>568.0</td>
<td></td>
</tr>
</tbody>
</table>

Meteorological Department, Mampong-Ashanti, Ghana (2017, 2018).

**Data collection and analysis**

Data were collected on sixty plants from the two middle rows and the means were taken. The quantitative traits measured were number of branches per plant, plant height, number of plants harvested, number of pods per plant, 100-seed weight and pod yield (t ha⁻¹). Number of branches per plant was counted from the two harvestable areas. Plant height was measured on three plants from the two middle rows with meter rule. Number of plants harvested and number of pods per plant were counted from the two middle rows on the day of harvest. The 100-seed weight was determined by randomly sampling 100 seeds from the two middle rows and the weight determined using electronic weighing scale. Data collected were subjected to ANOVA using GenStat Statistical Package, version 11.1. Least significant difference (LSD) was used to separate means at 5% level of probability.

**RESULTS**

**Vegetative growth**

**Number of branches per plant**

There was a significant difference between Adepa from Yenyawoso in terms of number of branches per plant for the entire 2017 and 2018 cropping seasons (Table 2a and b). The 50 cm × 10 cm and 60 cm × 10 cm single row pattern produced the same number of branches per plant at 30 days after planting (DAP) during the 2017 cropping season (Table 2a). The 50 cm × 10 cm and 60 cm × 10 cm single row pattern differed significantly from 50 cm × 20 cm × 20 cm and 60 cm × 20 cm × 20 cm twin row pattern in number of branches per plant at 30 DAP during the 2017 cropping season (Table 2a). The 50 cm × 10 cm single row pattern differed significantly from those planted on 50 cm × 20 cm × 20 cm and 60 cm × 20 cm × 20 cm twin row pattern in number of branches per plant for the entire growing period during the 2017 cropping season (Table 2a). There was no significant difference between variety × row pattern interaction in number of branches per plant in 2017 cropping season (Table 2a). The 50 cm × 10 cm differed significantly from other spacing at 30 DAP and 58 DAP in number of branches during the 2018 cropping season (Table 2b). There was no significant difference between single row and twin row pattern in number of branches per plant at 44, 72 and 86 DAP during the 2018 cropping season (Table 2b). There was a significant difference between variety × row planting spacing and pattern in number of branches per plant at 58 DAP and 86 DAP during the 2018 cropping season (Table 2b).

**Plant height**

There was a significant difference between Yenyawoso from Adepa in plant height at 44 DAP during the 2017 cropping season (Table 3a). However, Adepa had significantly taller plants from Yenyawoso at 86 DAP in the same cropping season. There was no significant difference between variety at 30 DAP and from 58 DAP to 72 DAP in plant height in 2017 cropping season (Table 3a). The 50 cm × 10 cm single row pattern produced significantly taller plant than 50 cm × 20 cm × 20 cm and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP during the 2017 cropping season (Table 3a). There was no significant difference between row pattern in plant height from 44 DAP to 86 DAP at the same cropping period (Table 3a). There was no significant difference between variety × row pattern interaction in plant height for the entire 2017 growing period (Table 3a). There was a significant difference between Adepa from Yenyawoso in plant height at 30 DAP during the 2018 cropping season (Table 3b). However, Yenyawoso had significantly taller plants than Adepa from 44 DAP to 86 DAP in the same cropping season. There was no significant difference between single row pattern as well as with twin row pattern in plant height for the entire 2018 growing period (Table 3b). The 60 cm × 10 cm single row pattern produce significantly taller plants than 50 cm × 20 cm × 20 cm twin row pattern for the entire 2018 growing season. There was no significant difference between variety × row pattern interaction in plant height for the entire growing period in 2018 (Table 3b).

**Yield and yield components**

**Number of plants harvested**

Yenyawoso and Adepa had the same number of plants
Table 2a. Number of branches per plant as influenced by variety and row pattern- 2017 cropping season.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>30 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
<th>72 DAP</th>
<th>86 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adepa</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Yenyawoso</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>5.5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>11.5</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>0.85</td>
<td>0.98</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Row pattern</th>
<th>30 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
<th>72 DAP</th>
<th>86 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 cm × 10 cm</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>60 cm × 10 cm</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>50 cm × 20 cm × 20 cm</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>60 cm × 20 cm × 20 cm</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Mean</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>11.7</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>1.2</td>
<td>1.39</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td>Variety × Row Pattern Interaction</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 2b. Number of branches per plant as influenced by variety and row pattern- 2018 cropping season.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>30 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
<th>72 DAP</th>
<th>86 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adepa</td>
<td>10</td>
<td>18</td>
<td>31</td>
<td>37</td>
<td>36</td>
</tr>
<tr>
<td>Yenyawoso</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Mean</td>
<td>8.5</td>
<td>13.5</td>
<td>20.5</td>
<td>22.5</td>
<td>22.5</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>1.48</td>
<td>2.22</td>
<td>1.83</td>
<td>3.47</td>
<td>2.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Row pattern</th>
<th>30 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
<th>72 DAP</th>
<th>86 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 cm × 10 cm</td>
<td>10</td>
<td>14</td>
<td>20</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>60 cm × 10 cm</td>
<td>9</td>
<td>14</td>
<td>17</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>50 cm × 20 cm × 20 cm</td>
<td>7</td>
<td>12</td>
<td>20</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>60 cm × 20 cm × 20 cm</td>
<td>8</td>
<td>13</td>
<td>23</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Mean</td>
<td>8.5</td>
<td>13.3</td>
<td>20</td>
<td>22.7</td>
<td>22.5</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>2.09</td>
<td>NS</td>
<td>2.6</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Variety × Row Pattern Interaction</td>
<td>NS</td>
<td>NS</td>
<td>3.67</td>
<td>NS</td>
<td>5.51</td>
</tr>
</tbody>
</table>

harvested and were not significantly different during the 2017 cropping season (Table 4). The 60 cm × 10 cm single row pattern and 50 cm × 20 cm × 20 cm twin row pattern had the same number of plants harvested and not significantly different in 2017 cropping season (Table 4). There was a significant difference between Yenyawoso from Adepa in number of plants harvested during the 2018 cropping season (Table 4). There was no significant difference between Yenyawoso and Adepa in number of plants harvested during the 2018 cropping season although differences exist between treatment (Table 4).

There was no significant difference between Adepa and Yenyawoso in number of pods per plant during the 2017 cropping season (Table 4). There was no significant difference between row pattern in number of pods per plant during the 2017 cropping season although differences exist between treatment (Table 4). Adepa
Table 3a. Plant height as influenced by variety and row pattern - 2017 cropping season.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>30 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
<th>72 DAP</th>
<th>86 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adepa</td>
<td>10.3</td>
<td>18.9</td>
<td>33.6</td>
<td>45.2</td>
<td>58</td>
</tr>
<tr>
<td>Yenyawoso</td>
<td>10</td>
<td>21.2</td>
<td>36.4</td>
<td>45.5</td>
<td>54.6</td>
</tr>
<tr>
<td>Mean</td>
<td>10.1</td>
<td>20</td>
<td>35</td>
<td>45.3</td>
<td>56.3</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>NS</td>
<td>1.77</td>
<td>NS</td>
<td>NS</td>
<td>3.35</td>
</tr>
<tr>
<td>Row pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 cm x 10 cm</td>
<td>11.6</td>
<td>20</td>
<td>36.4</td>
<td>45.4</td>
<td>56</td>
</tr>
<tr>
<td>60 cm x 10 cm</td>
<td>10.6</td>
<td>19.4</td>
<td>35.2</td>
<td>46.7</td>
<td>56.3</td>
</tr>
<tr>
<td>50 cm x 20 cm x 20 cm</td>
<td>9.7</td>
<td>20.2</td>
<td>35.3</td>
<td>45.6</td>
<td>57.1</td>
</tr>
<tr>
<td>60 cm x 20 cm x 20 cm</td>
<td>8.7</td>
<td>18.6</td>
<td>33.3</td>
<td>43.7</td>
<td>55.8</td>
</tr>
<tr>
<td>Mean</td>
<td>8.7</td>
<td>18.6</td>
<td>33.3</td>
<td>43.7</td>
<td>55.8</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>0.77</td>
<td>1.58</td>
<td>4.49</td>
<td>2.88</td>
<td>3.12</td>
</tr>
<tr>
<td>Variety x Row Pattern Interaction</td>
<td>10.1</td>
<td>20</td>
<td>35</td>
<td>45.3</td>
<td>56.3</td>
</tr>
<tr>
<td></td>
<td>2.01</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 3b. Plant height as influenced by variety and row pattern - 2018 cropping season.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>30 DAP</th>
<th>44 DAP</th>
<th>58 DAP</th>
<th>72 DAP</th>
<th>86 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adepa</td>
<td>8.2</td>
<td>15</td>
<td>25.8</td>
<td>26.6</td>
<td>29.1</td>
</tr>
<tr>
<td>Yenyawoso</td>
<td>7.3</td>
<td>19.7</td>
<td>31.6</td>
<td>33.2</td>
<td>35.7</td>
</tr>
<tr>
<td>Mean</td>
<td>7.7</td>
<td>17.3</td>
<td>28.7</td>
<td>29.9</td>
<td>32.4</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>0.77</td>
<td>1.58</td>
<td>4.49</td>
<td>2.88</td>
<td>3.12</td>
</tr>
<tr>
<td>Row pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 cm x 10 cm</td>
<td>8.9</td>
<td>19.5</td>
<td>31.6</td>
<td>31.4</td>
<td>35.1</td>
</tr>
<tr>
<td>60 cm x 10 cm</td>
<td>8.7</td>
<td>18.8</td>
<td>33.3</td>
<td>34</td>
<td>36.3</td>
</tr>
<tr>
<td>50 cm x 20 cm x 20 cm</td>
<td>7.2</td>
<td>17</td>
<td>27</td>
<td>29.3</td>
<td>31.4</td>
</tr>
<tr>
<td>60 cm x 20 cm x 20 cm</td>
<td>6.3</td>
<td>14.2</td>
<td>22.8</td>
<td>24.9</td>
<td>26.9</td>
</tr>
<tr>
<td>Mean</td>
<td>6.3</td>
<td>14.2</td>
<td>22.8</td>
<td>24.9</td>
<td>26.9</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>0.77</td>
<td>1.58</td>
<td>4.49</td>
<td>2.88</td>
<td>3.12</td>
</tr>
<tr>
<td>Variety x Row Pattern Interaction</td>
<td>7.7</td>
<td>17.3</td>
<td>28.7</td>
<td>29.9</td>
<td>32.4</td>
</tr>
<tr>
<td></td>
<td>1.09</td>
<td>2.24</td>
<td>6.35</td>
<td>4.07</td>
<td>4.42</td>
</tr>
</tbody>
</table>

There was a significant difference between Yenyawoso and Adepa in 100 - seed weight in both 2017 and 2018 cropping seasons (Table 5). There was no significant difference between row pattern in 100 - seed weight although differences exist among treatments in both 2017 and 2018 cropping seasons (Table 5). There was no significant difference between variety x row pattern interaction in 100 - seed weight in both 2017 and 2018 cropping seasons (Table 5). Yenyawoso and Adepa differed significantly from Yenyawoso in number of pods per plant during the 2018 cropping season. There was no significant difference between 50 cm × 20 cm × 20 cm from 60 cm × 20 cm × 20 cm twin row pattern as well as between 50 cm × 10 cm and 60 cm × 10 cm single row pattern. There was a significant difference between 60 cm × 20 cm × 20 cm twin row pattern from 50 cm × 10 cm and 60 cm × 10 cm single row pattern. There was no significant difference between variety x row pattern interaction in number of pods per plant during the 2018 cropping season (Table 4).
Table 4. Number of plants harvested and number of pods per plant as influenced by variety and row pattern- 2017 and 2018 cropping seasons.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of plants harvested</th>
<th>Number of pods per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>Variety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adepa</td>
<td>50</td>
<td>32</td>
</tr>
<tr>
<td>Yenyawoso</td>
<td>50</td>
<td>38</td>
</tr>
<tr>
<td>Mean</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>NS</td>
<td>4</td>
</tr>
<tr>
<td>Row pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 cm x 10 cm</td>
<td>48</td>
<td>38</td>
</tr>
<tr>
<td>60 cm x 10 cm</td>
<td>51</td>
<td>40</td>
</tr>
<tr>
<td>50 cm x 20 cm x 20 cm</td>
<td>51</td>
<td>34</td>
</tr>
<tr>
<td>60 cm x 20 cm x 20 cm</td>
<td>51</td>
<td>29</td>
</tr>
<tr>
<td>Mean</td>
<td>50</td>
<td>35.2</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>NS</td>
<td>5.67</td>
</tr>
<tr>
<td>Variety x Row Pattern Interaction</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 5. 100 - seed weight (g) and Yield (t ha⁻¹) as influenced by variety and row pattern- 2017 and 2018 cropping seasons.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>100 - seed weight (g)</th>
<th>Yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>Variety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adepa</td>
<td>70.4</td>
<td>76</td>
</tr>
<tr>
<td>Yenyawoso</td>
<td>56.4</td>
<td>69.2</td>
</tr>
<tr>
<td>Mean</td>
<td>63.4</td>
<td>72.6</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>7.85</td>
<td>5.45</td>
</tr>
<tr>
<td>Row pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 cm x 10 cm</td>
<td>67.5</td>
<td>71.2</td>
</tr>
<tr>
<td>60 cm x 10 cm</td>
<td>62.2</td>
<td>70.5</td>
</tr>
<tr>
<td>50 cm x 20 cm x 20 cm</td>
<td>63.7</td>
<td>73.3</td>
</tr>
<tr>
<td>60 cm x 20 cm x 20 cm</td>
<td>60.3</td>
<td>75.3</td>
</tr>
<tr>
<td>Mean</td>
<td>60.3</td>
<td>75.3</td>
</tr>
<tr>
<td>LSD (P ≤ 0.05)</td>
<td>7.85</td>
<td>5.45</td>
</tr>
<tr>
<td>Variety x Row Pattern Interaction</td>
<td>63.4</td>
<td>72.6</td>
</tr>
<tr>
<td></td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

planted on both single and twin row pattern during the 2018 cropping season had heavier 100 - seed weight than those planted on same during the 2017 cropping season (Table 5).

Yield (t ha⁻¹)

The yield varies between 3.73 - 3.94 t ha⁻¹ and 5.12 - 5.86 t ha⁻¹ in variety and 3.29 - 4.30 t ha⁻¹ and 4.81 - 6.70 t ha⁻¹ in row pattern during 2017 and 2018 cropping seasons respectively (Table 5). There was no significant difference between variety, row pattern and their interaction in yield during 2017 and 2018 cropping seasons although differences exist among treatment (Table 5). Adepa and Yenyawoso planted on both single and twin row pattern during the 2018 cropping season had higher yield than those planted on same during the 2017 cropping season.
Plant density is an indication of the number of plants per plot. It seems that the competition for light and nutrients (Hamakareem et al., 2016) results in canopy closure, which might have affected the growth and development of plants. The significant effect of Adepa and Yenyawoso in plant height is determined by the efficiency with which plant population density is achieved. Factors such as soil moisture, temperature and plant spacing can also affect growth and development. Inadequate space for lateral growth could be due to differences in genetic characteristics of cultivars. Variations in plant height observed in this study confirm the findings of Dapaah et al. (2014) and Konlan et al. (2013), who reported variations among cultivars in plant height. The significantly taller plants produced by Adepa at 30 cm × 10 cm, 60 cm × 10 cm, 50 cm × 20 cm, 20 cm × 20 cm, and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP and for the entire growing season in 2017 and 2018 respectively could be attributable to close intra row spacing and single row pattern. The significantly taller plants produced by Yenyawoso at 20 cm × 10 cm, 60 cm × 10 cm, 50 cm × 20 cm, 20 cm × 20 cm, and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP and for the entire growing season in 2017 and 2018 respectively could be attributable to close intra row spacing and single row pattern. Higher number of plants harvested during the 2018 cropping season could be due to differences in genetic traits and its response to the environmental resources. Both groundnut cultivars are semi-erect type as a genetic characteristic and their response to the environmental resources might have affected their growth differently. The variations in plant height observed in this study confirm the findings of Dapaah et al. (2014) and Konlan et al. (2013), who reported variations among cultivars in plant height. The significantly taller plants produced by Adepa at 30 cm × 10 cm, 60 cm × 10 cm, 50 cm × 20 cm, 20 cm × 20 cm, and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP and for the entire growing season in 2017 and 2018 respectively could be attributable to close intra row spacing and single row pattern. The significantly taller plants produced by Yenyawoso at 20 cm × 10 cm, 60 cm × 10 cm, 50 cm × 20 cm, 20 cm × 20 cm, and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP and for the entire growing season in 2017 and 2018 respectively could be attributable to close intra row spacing and single row pattern. The significantly taller plants produced by Adepa at 30 cm × 10 cm, 60 cm × 10 cm, 50 cm × 20 cm, 20 cm × 20 cm, and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP and for the entire growing season in 2017 and 2018 respectively could be attributable to close intra row spacing and single row pattern. The significantly taller plants produced by Yenyawoso at 20 cm × 10 cm, 60 cm × 10 cm, 50 cm × 20 cm, 20 cm × 20 cm, and 60 cm × 20 cm × 20 cm twin row pattern at 30 DAP and for the entire growing season in 2017 and 2018 respectively could be attributable to close intra row spacing and single row pattern.
groundnut grown on low plant densities, benefit from more water, solar energy and nutrition. The higher number of plants harvested during the 2017 cropping season than during the 2018 cropping season could be linked to tall plants produced in 2017. The close and positive relationship between the two groundnut varieties, row patterns in number of plants harvested and plant height during the 2017 growing season might have contributed to this observation. The tall plants produced might have enhanced light interception and utilization, hence high number of plants surviving until harvesting. Light interception is highly influenced by different planting patterns, and the more efficient capture and use of light contribute to yield advantages (Wang et al., 2017).

**Number of pods per plant**

The non-significant difference between varieties and row pattern in number of pods per plant during the 2017 cropping season could be that row pattern had no effect on variety. The significantly higher number of pods per plant produced by Adepa over Yenyawoso in 2018 cropping season could be due to differences in genetic trait and its response to high rainfall experienced during the growing period. The significant difference between 60 cm × 20 cm × 20 cm twin row pattern from 50 cm × 10 cm and 60 cm × 10 cm single row pattern in number of pods per plant could be attributed to wider spacing and twin row pattern. As the number of plants per unit area decrease, thus at low plant density competition for growth resources such as water, nutrient and light decrease. This is in conformity with earlier findings by Arioglu et al. (2017); Dapaah et al. (2014) and Konlan et al. (2013). Jaiswal et al. (2018) reported that wider spacing of 30 cm × 15 cm proved superior in increasing number of pods per plant than closer spacing of 22.5 cm × 10 cm. Wider spacing might have decreased inter and intra-specific competition for crop growth resources compared to narrow spaced plant. Crop yield is determined by the efficiency with which plant population use available environmental resources such as nutrient, light and water for growth (Onat et al., 2016; Angelucci and Bazzuchi, 2013).

**Total yield (t ha⁻¹)**

The higher yield produced in both cultivars and row pattern during the 2018 cropping season than in 2017 could be due to high rainfall experienced during the 2018 cropping period. Seasonal changes to rainfall could lead to changes in soil water content, which is likely to affect plant growth and yield. The higher rainfall experienced in 2018 than in 2017 cropping seasons might have enhanced plants to produce more leaves, large leaf area and canopy spread to maximize light interception during growth and reproductive stages for high yield. Lack or inadequate rainfall during flowering and pod setting causes substantial decrease in yield. The production of high yield in Adepa than Yenyawoso in both 2017 and 2018 cropping seasons may be linked to high production of number of branches per plant in Adepa at 86 DAP. This agrees with Dapaah et al. (2014) that nodes of branches are potential sites for peg development and subsequent pod formation and that branching characteristics is an important agronomic traits for crop yield. Konlan et al. (2013) reported higher yield in Adepa than other four groundnut varieties in northern Ghana. The higher yield in 50 cm × 20 cm × 20 cm twin row pattern during the 2018 cropping season than same during the 2017 cropping season and the other row patterns may be attributed to wider spacing and twin row pattern. Wider spacing might have decreased inter and intra plant competition for resources such as moisture, nutrient and light. This agrees with Arioglu et al. (2017) and Onat et al. (2016). Planting spacing, row pattern, plant density and branching are some of the most important factors that may have direct influence on crop yield. There was a close and positive relationship with number of branches per plant at 86 DAP and pod yield with 50 cm × 20 cm × 20 cm twin row pattern in 2018 cropping season. Branching in groundnut may impact positively on yield since the branches bear the leaves and also determine the canopy spread and closure and solar interception and utilization (Dapaah et al. 2014). This is in support of Onat et al. (2016) that at low plant density, existing plants developed more branches and pegs because of reduction in competition.

**100 - Seed weight**

Adepa produced significantly higher 100 - seed weight than Yenyawoso in both cropping seasons. This might be due to differences in genetic characteristics. Konlan et al. (2013) earlier reported that Adepa with bunch semi-erect growth habit produced heavier 100- seed weight than other local varieties which were of the bunch semi-erect types. The 50 cm × 20 cm × 20 cm and 60 cm × 20 cm × 20 cm twin row pattern produced heavier 100 - seed weight than 50 cm × 10 cm and 60 cm × 10 cm single row pattern during the 2018 cropping season. This might probably be due to the highest number of pods per plant produced. There was a close and positive relationship between number of pods per plant 100 - seed weight during the 2018 cropping season. The low plant density might have contributed to decreased inter and intra-specific competition for growth resources and compensated for by the increased pods number per plant giving high 100 - seed weight. Increased in 100 - seed weight with decreased plant density with wider spacing have also be reported by Dapaah et al. (2014) and Konlan et al. (2013). The variety x row pattern interaction
effects for 100 - seed weight was not significant in both years.

Conclusion

In conclusion groundnut can be cultivated in the forest-savannah transition zone of Ghana for high vegetative biomass, pod yield and heavy seeds. Farmers are encouraged to grow preferably Adepa cultivar of groundnut under initial high rainfall condition for proper crop growth in terms of high number of branches and tall plants and also for high yield. Groundnut should be planted using 50 cm × 20 cm × 20 cm and 60 cm × 20 cm × 20 cm twin row pattern for high vegetative biomass, yield and quality seeds in terms of heavy seeds. Interaction effect between variety × row pattern was significant with number of branches per plant at 58 DAP and 86 DAP during the 2018 cropping season. This is an indication that row pattern had effect on variety and with higher rainfall and lower temperature experienced during the 2018 growing period compared to 2017 cropping period the growth of more branches per plant was enhanced. Nodes on branches are the potential sites for peg development and subsequent pod formation hence high yield in groundnut. Groundnut can be influenced by environmental factors such as soil moisture, temperature and plant density and that the growth and development of a crop is determined by the efficiency with which plant population uses available resources.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES


Yield evaluation and character association of linseed (*Linum usitatissimum* L.) genotypes in moisture stress areas of South Tigray, Ethiopia

Birhanu Amare Gidey

Alamata Agricultural Research Center, Pulse and oil Crops Case team, P. O. Box 56, Tigray, Ethiopia.

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Linseed (*Linum usitatissimum* L.) is one of the most important highland oil crops of southern Tigray, Ethiopia and it is considered as the least expensive source for oil related home consumptions. The 12 genotypes of linseed including two standard checks were evaluated in the highland and moisture stress area of Southern Tigray under rain fed condition with the objective of evaluating yield and yield components as well as their association. Observations were recorded for different characters, viz., days to maturity, plant height, and number of capsules per plant, number of seeds per capsule, 1000-seed weight and seed yield. Highly statistical significant (P < 0.01) differences were found among the genotypes for days to maturity, plant height and seed size. The standard checks (Bekoji and Kassa -2) were matured late (122 days after emergence) in the growing area as compared with the other genotypes. These genotypes had long plant height (89.4 and 87.3 cm, respectively) and they showed higher significant difference. Genotypes 20-Marc, 8-Marc, 4-Marc, 11-Marc and 31-Marc were matured with in 103, 104, and 105 days in that order and they were earlier as compared to others. Mean seed yield had positive correlation with all yield components except 1000 seed weight. Significantly higher positive significant correlation was observed among days to maturity and plant height (r = 0.73). Plant height also showed positively and significantly correlation with seed weight (0.54). Therefore, strong and positive association between seed yield and some of yield related traits provide the opportunity to improve seed yield and other desirable traits of linseed.

**Key words:** Correlation, genotype (entry or variety), linseed, yield component.

**INTRODUCTION**

Linseed (2n = 30) is an important oilseed and fiber crop which belongs to the family Linaceae (as cited by Mulusew et al. (2013). It is believed that this crop species may have originated from *Linum angustifolium* Huds. (2n = 30) native to the Mediterranean region (Cooke, 1903; Legesse, 2010). Linseed is an annual field crop that is largely grown in temperate areas of the world (Mansby et al., 2000) and cool tropics including highland areas of Ethiopia.
Ethiopia with its altitude ranging from 2500 m. above sea level and more. It is the second most important oil crop in the highlands of Ethiopia in terms of area coverage and production (Adefris et al., 1992; Adugna, 2000). Linseed requires cool temperatures ranging from 10 to 30°C although the crop grows best within 21 and 22°C during its growing period to produce good yields. According to Adugna (2007), Ethiopia is considered to be the secondary center of diversity, and now the 5th major producer of linseed in the world after Canada, China, United States and India. The crop performs best in altitudes ranging from 2200 to 2800 meters above sea level (Tesfaye, 2017). The wide range of agro-climatic conditions in Ethiopia may have contributed to its wider diversification for this oil crop. In the 2015-2016 cropping season, 85,415.67 ha of land was covered in Ethiopia with linseed and the production was estimated to be 885,511.44 quintals (MoANR, 2016).

In Ethiopia, linseed has been cultivated primarily for seed and oil purposes. Linseed oil content is mainly in the range of 35 - 44% with drying oil properties (Tesfaye et al., 2016). The seed is commonly roasted, ground and mixed with spices and some water to be served along with local breads. It also consumed in soups, soft drinks and with porridge cooked potatoes. Its industrial use is higher than all other oil crops. It has traditionally been used for food and as a cash crop since ancient times. Its seeds are usually roasted, ground, mixed with spices and water, and served with various local consumptions. Linseed oil has been used for edible purpose in the past years.

The ground seed is of great value for a number of purposes including gastric pain and the extracted mucilage is used in cosmetic and pharmaceutical industries (Hiruy and Nigussie, 1988). The oil is also used as a raw material for a number of industrial products, such as drying agents, paintings and varnishes, soap manufacture, printing inks etc., whereby it lends itself as an export commodity, thus, contributing a lot towards building the national economy (Reta and Nigussie, 2017).

The highland areas of Southern Tigray are one of the potential areas for the production of highland oil crops in Ethiopia, and linseed is the only main oil crop grown in the area. Despite its potential and profitability, the crop has been traditionally grown on marginal lands using local variety. No improved linseed variety has been grown in the area and the locally cultivated accessions (land races) are not yet collected and tested for their yield potential and other yield components. On the contrary, there is a sever shortage of edible oil in the country (Ethiopia) in general and the Tigray region in particular. Hence, the objective of this study is to evaluate the overall performances of the locally collected accessions (landraces) and released linseed varieties to increase the production and productivity of the crop and contributes to minimize the edible oil shortage in the country as well as to exploit the linseed production capacity for domestic uses and export purposes.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in the field of farmers’ training center found at Mekhan kebble of Endamekoni district, Southern Tigray, Ethiopia during the main cropping season of 2019. Mekhan FTC is located at the distance of 660 km from Addis Ababa (the capital city of Ethiopia) and 125 south of Mekelle. This center is also found at about 12°33’21” N latitude, 39°25’28” E longitude and at an altitude of about 2480 m above sea level (Amanuel et al., 2015). The area is characterized by moisture stress agro-ecology but bimodal rainfall pattern. According to Amanuel et al. (2015), the minimum and maximum annual temperature of the study area is 8-25°C, respectively and the annual rainfall distribution ranges from 600 - 800 mm.

Experimental materials

Twelve entries (genotypes) of linseed including two standard checks were collected from Tigray region and evaluated in the study area. The experiment was laid out in a randomized complete block design with three replications. The plot size was 1.2 × 5 m with spacing of 20 cm between rows and drilling method of sowing. The four central rows were used for data collection and all agronomic practices were done as per the recommendations.

Collected data and analysis of variance

The yield and yield component parameters were collected that include days to physiological maturity, plant height, number of capsules per plant, number of seeds per capsule, 1000 seeds weight and seed yield. The collected data were analyzed using the standard procedure applicable to randomized complete block design as suggested by Gomez and Gomez (1984) using GenStat (Payne et al., 2007) version 16 software programs and least significance difference was used for the mean comparison both at 1 and 5% probability level.

RESULTS AND DISCUSSION

Analysis of variance and estimation of variance components

The mean days to maturity, 1000 seed weight, plant height, number of capsules per plant, number of seeds per capsule and seed yield were analyzed. A higher significant (P < 0.01) difference was observed on the genotypes for days to maturity, plant height and thousand seed weight (Table 1). This finding is in consistent with Tesfaye et al. (2016). Non-significant (P > 0.05) differences were observed among the genotypes for seed yield, number of capsules per plant and number of seed per capsule.

The standard checks (Bekoji and Kassa -2) matured late (122 days after emergence) in the growing area as compared with the other genotypes. However, genotypes 20-Marc, 8-Marc, 4-Marc, 11-Marc and 31-Marc matured...
within 103, 104, and 105 days in that order and they were earlier in days to maturity. In similar manner, both the standard checks varieties had long plant height (89.4 and 87.3 cm) and they showed highest significant (P < 0.01) difference with the other genotypes (Table 1).

### Performance of seed yield and seed size of linseed genotypes

The seed yield has revealed that no significant (P > 0.05) variation was observed among the genotypes of linseed. However, numerically genotypes 28-32 Marc, Bekoji, and 237001 gave higher seed yield as 2194, 2182, 2167 kg ha⁻¹, respectively. The character tested previously in Ethiopia and other countries, the mean seed yield obtained in this research is higher and very appreciable even in most or all tested materials. For example in Ethiopia, lower seed yield is recorded in different research results conducted and displayed by various professionals (Tesfaye et al., 2016; Lirie et al., 2013; Abebe et al., 2010; Yared and Miteru, 2016). This could be related to the suitability of the agro-ecology of the area to these tested and higher yields genotypes. Very high significant (P < 0.01) difference was observed among the tested linseed genotypes for seed size (Table 1). The Bekoji, Kassa-2, 11-Marc and 4-Marc gave highest and similar 1000 seed weight (5.733, 5.667, 5.267 and 5.201 g, respectively) and there was non-significant difference among the genotypes. On the other hand, even though they showed similar p-value with some other genotypes, entry 237001 and 234008t scored lowest seed weight (4.400 g 1000⁻¹).

### Correlation of seed yield with other characters

Correlation coefficient estimates degree of association of different linseed yield and yield components among themselves. Based on this, the values of Pearson correlation coefficient revealed that days to maturity and plant height showed highly significant and positive correlation (0.73). This situation was observed in Bekoji and Kassa-2 genotypes which had long plant height as a result of late days to maturity. This result is in consonance with Yared and Miteru (2016) and Reddy et al. (2013). Mean plant height had significant positive correlation with number of capsules per plant. Similar findings were reported by Dashe et al. (2016), Naik and Satapathy (2002) and Savita (2006).

Even though there was no significant correlation of seed yield with days to maturity, number of capsules per plant, number of seeds per capsule and plant height, the relationship was positive (Table 2). Similar results were reported by Dash et al (2016); Tesfaye et al. (2016) and Tadesse et al. (2009). Therefore, number of seeds per capsule (0.114), days to maturity (0.18) and plant height (0.19) showed a low positive direct effect on the seed yield genotypes (Ibrar et al., 2016).

On the other hand, seed yield has negative correlation with 1000 seed weight in very low amount (r = -0.0896). This result is in agreement with Yadav et al. (2017) and Dash et al. (2016). Thousand seed weight has significant and positive association (r = 0.5358) with plant height but non-significantly correlation with days to maturity and number of capsules per plant (r = 0.27 and 0.28, respectively). The 1000 seed weight correlates with number of seeds per capsule negatively (r = -0.33), that

### Table 1. Mean Seed yield and other agronomic characters of linseed genotypes.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>DM</th>
<th>PHT (cm)</th>
<th>NCPP</th>
<th>NSPC</th>
<th>TSW (g)</th>
<th>SY (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-Marc</td>
<td>103</td>
<td>62.0</td>
<td>32</td>
<td>7.9</td>
<td>4.933</td>
<td>1980</td>
</tr>
<tr>
<td>8-Marc</td>
<td>104</td>
<td>61.5</td>
<td>25</td>
<td>7.8</td>
<td>4.667</td>
<td>1836</td>
</tr>
<tr>
<td>4-Marc</td>
<td>105</td>
<td>64.3</td>
<td>31</td>
<td>9.0</td>
<td>5.200</td>
<td>1910</td>
</tr>
<tr>
<td>11-Marc</td>
<td>105</td>
<td>61.3</td>
<td>28</td>
<td>8.3</td>
<td>5.267</td>
<td>1698</td>
</tr>
<tr>
<td>31-Marc</td>
<td>105</td>
<td>60.9</td>
<td>27</td>
<td>8.1</td>
<td>4.933</td>
<td>1865</td>
</tr>
<tr>
<td>19-Marc</td>
<td>108</td>
<td>64.1</td>
<td>33</td>
<td>8.1</td>
<td>4.867</td>
<td>1950</td>
</tr>
<tr>
<td>234008t</td>
<td>112</td>
<td>68.1</td>
<td>23</td>
<td>8.5</td>
<td>4.400</td>
<td>1945</td>
</tr>
<tr>
<td>22-Marc</td>
<td>113</td>
<td>61.6</td>
<td>25</td>
<td>8.0</td>
<td>4.867</td>
<td>1997</td>
</tr>
<tr>
<td>28-32 Marc</td>
<td>115</td>
<td>68.0</td>
<td>23</td>
<td>8.5</td>
<td>4.533</td>
<td>2194</td>
</tr>
<tr>
<td>237001</td>
<td>116</td>
<td>65.5</td>
<td>30</td>
<td>8.3</td>
<td>4.400</td>
<td>2167</td>
</tr>
<tr>
<td>Bekoji</td>
<td>122</td>
<td>89.4</td>
<td>31</td>
<td>7.5</td>
<td>5.667</td>
<td>2182</td>
</tr>
<tr>
<td>Kassa-2</td>
<td>122</td>
<td>87.3</td>
<td>25</td>
<td>7.7</td>
<td>5.733</td>
<td>1836</td>
</tr>
<tr>
<td>Mean</td>
<td>110.7</td>
<td>67.8</td>
<td>28</td>
<td>8.1</td>
<td>5.0</td>
<td>1963</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>4.316**</td>
<td>8.312**</td>
<td>NS</td>
<td>NS</td>
<td>0.542**</td>
<td>NS</td>
</tr>
<tr>
<td>CV (%)</td>
<td>2.3</td>
<td>7.2</td>
<td>21</td>
<td>6.9</td>
<td>6.5</td>
<td>14.8</td>
</tr>
</tbody>
</table>

NS = Non-significant difference, DM = Days to maturity, PHT = Plant height, NCPP = Number of capsules per plant, NSPC = Number of seeds per capsule, TSW = Thousand seed weight, SY = Seed yield.
is, a decrease was observed in seed weight with increasing number of seeds per capsule. Dash et al. (2016) and Mahto and Rahaman (1998) found negative correlation with number of seeds per capsule and 1000-seed weight. The mean number of capsules per plant had positive but non-significant difference correlation with plant height and 1000-seed weight. This is in consonance with the findings of Savita (2006). The number of seeds per capsule negatively correlates with most traits, that is, with days to maturity, number of capsules per plant, plant height, and seed size but only positively correlated with seed yield. Also Mahto and Rahaman (1998) and Naik and Satapathy (2002) had result similar with this result. The strong and positive association between seed yield and some of yield related traits provides the opportunity to improve seed yield and other desirable traits simultaneously. Linseed traits that did not have significant correlation with seed yield indicate that selection for increased levels of these traits may not bring significant change in seed yield.

### Table 2. Correlation coefficients among the traits measured from twelve linseed genotypes.

<table>
<thead>
<tr>
<th>Trait</th>
<th>DM</th>
<th>PHT</th>
<th>NCPP</th>
<th>NSPC</th>
<th>TSW</th>
<th>SY</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHT</td>
<td>0.7283</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCPP</td>
<td>-0.0764</td>
<td>0.0125</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSPC</td>
<td>-0.1394</td>
<td>-0.2024</td>
<td>-0.0308</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSW</td>
<td>0.2664</td>
<td>0.5358</td>
<td>0.2762</td>
<td>-0.3329</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>SY</td>
<td>0.2233</td>
<td>0.2593</td>
<td>0.2278</td>
<td>0.0181</td>
<td>-0.0847</td>
<td>-</td>
</tr>
</tbody>
</table>

DM = Days to maturity, PHT = Plant height, NCPP = Number of capsules per plant, NSPC = Number of seeds per capsule, TSW = Thousand seed weight, SY = Seed yield.

### Conclusion

The days to maturity is an important parameter for the study areas as the testing location is characterized by moisture stress condition. Genotypes 20-Marc and 8-Marc showed earlier days to maturity with their reasonable seed yield and breeders should consider not only to seed yield but also to earlier physiological maturity of linseed entries selection. The yield components which include number of capsules per plant, number of seeds per capsule, plant height and seed size are the important selection parameters to improve linseed yield. Almost all of the above traits correlate positively with seed yield because these parameters had positive direct effect on the seed yield as their correlation values were in the positive direction.

### CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

### ACKNOWLEDGEMENTS

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### REFERENCES


Full Length Research Paper

Effect of germination on structural and physicochemical properties of starch in glutinous brown rice

Liyezi He, Chuan Cao, Jingwei Hu, Dongmei Wei, Li Xu, Tang Su and Yibin Zhou*

Anhui Engineering Laboratory for Agro-products Processing, Anhui Agricultural University, 130 Chang Jiang West Road, Hefei 230036, China.

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This study compared the structural and rheological properties of native (GB0), 12 h (GB12), 24 h (GB24), 36 h (GB36), 48 h (GB48) and 72 h (GB72) germinated glutinous brown rice starch to improve the market value of glutinous rice through germination. The proportion of A chains (DP 6-12) increases and the proportion of B1 chains (DP 13-24) decreased with germination time. Interestingly, we observed that the total proportion of B2 and B3 chains decreased, but was recovered after germination at 36 h. The effect of germination on the distribution of amylopectin length results in a decrease in relative crystallinity, gelatinisation temperature, gelatinisation enthalpy and pasting viscosities. In this study, we found that GB12 starch gel has the weakest thermal stability and its shear resistance is more difficult to retrogradation; while GB36 has the highest chain association (retrogradation) which is induced by cooling.

Key words: Glutinous brown rice, germination, starch, structural properties, rheological properties.

INTRODUCTION

Glutinous rice commonly referred to as sticky or waxy rice is characterised by its non-transparent surface and high amylopectin content. Such rice is widely processed into food products and has a high yield, particularly in China, where it is mainly used as material of traditional foods, such as Tangyuan, Zongzi, and Shaoxing wine, and as an added ingredient in other products. Glutinous rice starch is almost entirely amylopectin, with <2% amylose (Xu et al., 2013). The amylose–amylopectin ratio will influence the physicochemical properties of starch. Amylopectin exhibits poor syneresis and hard to retrogradation. As a result, compared with the boiled rice from a normal-amylose cultivar, the low-amylose cultivar is stickier (Noda et al., 2003). The crystallization of amylopectin in high-amylopectin cultivars will also contribute to their resistance to enzymatic digestibility (Liu et al., 1999). Consequently, such cultivars result in indigestion and are not suitable as staple food, resulting in a much lower market value.

Compared with ordinary milled rice grains, brown rice grains are nutrient-rich, for example dietary fibres, vitamins, phytic acids, gamma aminobutyric acid, and

*Corresponding author. E-mail: zhoyibin@ahau.edu.cn. Tel: +86 13095515977.

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vitamins, etc (Komatsu et al., 2007). Because of the highly nutritional value of GBR, its products are popularity in health-conscious consumers in Asian. Despite its elevated nutritional content, brown rice is not acceptable as table rice because of its poor water absorbency, expansibility in cooking, and poor texture. The rich tough of out bran layer keeps off water into the endotheicum of GBR, and leads to these shortcomings (Das et al., 2008). For this reason, the characters of brown rice have been improved by several new processing methods which developed in recent years, covering high hydrostatic pressure (Boluda-Aguilar et al., 2013; Xia et al., 2017; Wang et al., 2020), high-temperature fluidization (Jaisut et al., 2009), ultrasound (Cui et al., 2010), low-pressure plasma (Chen et al., 2016), and germination. During the process of germination, the degradation of high-molecular-weight polymers will result in generation of biofunctional substances and improved organoleptic qualities, resulting in a softened texture and increased flavour (Subba Rao and Muralikrishna, 2002). Starch accounts for about 90% of the total dry weight of rice, and the ease with which rice cooks and its overall taste is primarily affected by its starch properties. Amylopectin was the main component of most starches, and variations in the amylopectin fine structure will lead to different physicochemical properties. Many studies have examined the different characteristics between germinated and ungerminated brown rice starch (Xu et al., 2012; Musa et al., 2011). Pinkaew et al. (2016, 2017) only investigated the characteristics of the pre-germination stage of brown rice starches. Several researches have evaluated the impact of germination on the physiochemical properties of long-grain or round-grain brown rice starch (Wu et al., 2013; Li et al., 2017; Kalita et al., 2017). However, less research has been conducted to specifically examine germinated glutinous brown rice starch. The physicochemical properties of glutinous brown rice starch from germination at 36 h have only been evaluated by You et al. (2016), who examined the structural properties and the in vitro digestibility of native and 36-h germinated waxy brown rice starches, whereas other germination stages were not studied.

The aim of the present study was to compare the structural and rheological properties of glutinous brown rice starch at 0-72 h germination stages. Figure 1 These findings can help to (1) understand the effects of different germination time on the structural and physicochemical properties of starch, and (2) improve the texture and organoleptic qualities of glutinous brown rice through germination, and (3) provide a basis for the development of glutinous brown rice, and a reference for more effective use of germinated glutinous brown rice as an additive.

MATERIALS AND METHODS

Glutinous brown rice was harvested in 2019 and provided by Anhui Guangming Huaxiang Industry and Trade Group Co., Ltd (Anhui province, China), and stored at 4°C in a refrigerator.

Preparation of germinated glutinous brown rice

The glutinous brown rice grains (2000 g) were thoroughly rinsed with tap water and disinfected with 1% NaClO, followed by soaking in distilled water (pH = 7. grain to water ratio 1:2 w/v) at 25°C for 12 h; the distilled water was changed every 2 h. The rice grains were placed between wet gauze and sponge on a tray after soaking, then germinated in a constant temperature incubator (DHP-9162, Yiheng technology Co., Shanghai, China) for 72 h at 35°C and 65% humidity. The sample was obtained every 12 h. After germination for regular time, the native and germinated glutinous brown rice were dried at 45°C for 24 h.

Isolation of starch

The starch of the native glutinous brown rice (GB0), 12 h germinated glutinous brown rice (GB12), 24 h germinated glutinous brown rice (GB24), 36 h germinated glutinous brown rice (GB36), 48-h germinated glutinous brown rice (GB48) and 72 h germinated glutinous brown rice (GB72) were isolated by soaking in 0.1% NaOH solution using the procedure proposed by Lim et al. (1999). The extracted starches were continuously dried at 45°C for 1 d, and ground into powder by using a mechanical grinder (DSY-9002, Jiushunying Chamber Commerce Co., Zhejiang, China) and then passed through a 100-mesh sieve.

Amylopectin branch chain length distributions

The branch chain length distribution of the starches was determined by high performance anion exchange chromatography-pulsed amperometric detector (HPAEC–PAD). Sample (9 mg) was dissolved in 100% DMSO (450 µL) and stirred in a boiling water bath for 12 h. The starch solution was diluted with ultrapure water (2250 µL) and 300 µL of sodium acetate buffer (0.1 M, pH 4.5). Next, 1 µL of isoamylase and 1 µL of pullulanase were added to the sample solution and then stirred (100 rpm) at room temperature for 12 h. The enzymatic reaction was terminated by heating in a boiling water bath. After debranching, the sample solution was centrifuged and filtered through 0.45 µm nylon syringe filter before being injected into the HPAEC system (ICSS5000, Dionex, CA, USA); it was injected with Pulse ampere detector (PAD), using 150 mM NaOH and 500 mM sodium acetate in 150 mM NaOH at a flow rate of 1 mL/min to gradient elution separation.

X-ray diffraction

X-ray diffraction patterns were obtained by an X-ray diffractometer (X’Pert PRO, Philips Co., Almelo, Netherlands) which operated at 40 mA and 40 kV with scanning speed of 2.0°/min and scanning range of 3-60° (2θ). Using the Origin software (Version 8.0, Microcal Inc., Northampton, MA, USA) the two-phase method was followed to quantitatively calculate the relative crystallinity (Lopez-Rubio et al., 2008).

Differential scanning calorimetry

Using a differential scanning calorimeter (DSC8000, PerkinElmer Co., Norwalk, CT) to evaluate the thermal properties of the starches, 2 mg starch was weighed in aluminium crucibles. Then redistilled water (6 µL) was added with a pipette and mixed well with a fine needle. The crucibles had a sealing gland and were kept at
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Figure 1. Flow chart.

room temperature to equilibrate moisture for 24 h. The crucibles with a heating rate of 10°C/min were heated from 30 to 130°C. The onset (T_o), peak (T_p), and conclusion (T_c) temperatures, as well as the enthalpy of gelatinization (ΔH) were determined from the data recording software.

Rapid Visco Analyser

A Rapid Visco Analyser (RVA-TecMaster, Warriewood, Australia) was used to analyze the pasting properties of the starches. The starch suspension liquid was prepared (7% w/w, 30 g of total weight), and the temperature program was set as: held at 30°C for 1 min, heated to 95°C at a rate of 6°C/min, held at 95°C for 5 min, cooled to 30°C at 6°C/min, and finally held at 30°C for 2 min.

Dynamic rheological properties

Dynamic rheological properties were evaluated using an HAAKE RheoStress 6000 (Thermo Scientific, USA) with parallel plate system (4 cm plate diameter); the gap size was set at 1 mm, and measured with 0.5% of strain and 1 Hz of frequency. The dried starches were dispersed in distilled water (6% dry solids) by heating in a boiling water-bath for 30 min with stirring. The gelatinized sample was immediately transferred on the test board, and preheated to 95°C for the analysis. The free surface of the sample edges was covered with silicone oil to reduce evaporation losses during measurements. The storage (G’) and loss (G”) moduli were measured while the paste was cooled to 4°C at a rate of 1 °C /min. The dynamic viscoelastic properties, including elastic modulus (G’), viscous modulus (G”), and complex modulus, G* = (G’^2 + G”^2)^1/2 were recorded as a function of frequency.

Statistical analysis

The SPSS statistical software version 21.0 (SPSS Inc., Chicago, IL, USA) was employed to analyze the significant differences among means (P < 0.05) through Duncan’s multiple range test.

RESULTS AND DISCUSSION

Structural characterization

Figure 2 shows the normalized HPAEC-PAD chromatogram of the amylopectin branch chain length
distribution of the starches isolated from GB0, GB12, GB24, GB36, GB48 and GB72. Researchers divided the normalized amylopectin into four parts: A chains (DP 6–12), B1 chains (DP 13–24), B2 chains (DP 25–36), and B3 chains (DP 25– (Hanashiro et al., 1996). After germination, the proportion of A chains increased significantly; in contrast, the proportion of B2 chains decreased gradually. The total proportion of chain A and chain B1 increased. According to the starch cluster model of amylopectin, A and B1, chains formed double helix structure in starch granules, and was the most part external (Tester et al., 2004). Therefore, part of them are degraded to oligosaccharides to provide energy for the growing germs, which is due to the activation of hydrolyses during germination (Mohan et al., 2010). Interestingly, we observed that the total proportion of B2 and B3 chains decreased before germination at 36 h; it rose again at 36 h, and then continued to decrease with the extension of germination time. The enzymatic degradation at the beginning of germination may be the cause of this trend. The maximum limit of the amylopectin chain length was approximately 100. Nevertheless, in our HPAEC system, the super longer chains (DP > 78) could not be detected, but they can actually form the whole amylopectin macromolecules by connecting with each other into clusters. So, the super longer chains can degrade during germination and lead to the rise in the proportion of B2 and B3 chains of GB36 starch in this study (Hizukuri, 1985).

Crystalline structure

The starches isolated from GB0, GB12, GB24, GB36, GB48, and GB72 all exhibited the typical A-type diffraction pattern with individual peaks at 15° and 23° and unresolved peaks at 17° and 18°. From Figure 3 we could not find any significant changes in the X-ray diffraction pattern of starches after germination. The A-type diffraction pattern reflects a compact packing of amylopectin double helices (Khunae et al., 2007). Compared with the GB0 starch, the relative crystallinity of GB12 starch and GB24 starch had no significant difference.

This shows that the hydrolysis during germination primarily attacked the amorphous area of the starch granules before germination at 24 h. Nevertheless, when germination occurred at 36 h, germination did cause a lower relative crystallinity, and the relative crystallinity was decreased with the germination time. Relative crystallinity is possibly connected with the interaction of double helices (Jane et al., 1999). (Cooke and Gidley, 1992) confirmed that the existence of short amylopectin chains (DP<10) leads to the instability of the double helix. The proportion of DP 10-13 is negatively correlated with crystallinity which is confirmed by Cheetham and Tao (Cheetham and Tao, 1998). Therefore, a high-proportion of A chains in the starch of GB36, GB48 and GB72 may cause the decrease in the relative crystallinity.

Thermal properties

Table 1 presents the thermal properties of the starch samples obtained from GB0, GB12, GB24, GB36, GB48, and GB72. In this study, the gelatinisation temperature of the glutinous brown rice starch decreased slightly following germination. Similarly, You et al. (2016) also declared the gelatinization temperature decreased after germination. The molecular structure of crystalline regions which are related to the amylopectin branch chain length distributions can influence gelatinization temperatures. Thus, low gelatinization temperatures may have resulted from the high proportion of A chain and a less amount of long chain amylopectin (Pinkaew et al., 2017). In addition, the starch exhibited lower gelatinisation enthalpy during the germination. Similarly, Xu et al. (2012) and Li et al. (2017) also found the gelatinization enthalpy of germinated rice starches were lower than the native rice starches. The reduced gelatinization enthalpy after germination can confirm the fracture of the hydrogen bonds linking adjacent double helices (Chung et al., 2008). The damage of double helical order in crystalline and non-crystalline regions can normally be represented by gelatinization enthalpy (Cooke and Gidley, 1992). Gidley and Bulpin (1997) confirmed that the gelatinization enthalpy can also be impacted by the amylopectin branch chain length distributions. The lower proportion of long branch chains constitutes a shorter order of double helical and leads to smaller gelatinization enthalpy (Li et al., 2017).

Pasting properties

The differences of pasting properties between the starch of native and germinated glutinous brown rice are given in Figure 4. The behaviour exhibited was the same as that classically encountered in aqueous starch dispersions. In the present study, gradual decreases were observed in the pasting temperature and viscosities during the germination. Li et al. (2017) suggested that more rigid crystalline structure cannot swell easily. Chung et al. (2011) proposed that keeping the swollen granules in perfect condition needs strong interaction which could not be provided by the high proportion of short chains (DP 6-12) and resulted in lower pasting temperature and pasting viscosities. The higher proportion of A chains (DP 6-12) after germination may result in the decrease in pasting temperature. During germination, the α-1,4-glycosidic linkages of the starch molecules were broken by activated α-amylase which might explain the high dissolubility and easy saccharification of starch gel, leading to a lower peak viscosity (Zhu et al., 2010).

The breakdown of the glutinous brown rice starches was increased after germination. Keeping the swollen granules in perfect condition needs strong interaction
Figure 2. High-performance anion-exchange chromatography normalized chromatogram of native and germinated glutinous brown rice. GB, germinated glutinous brown rice starch; 0, 12, 24, 36, 48, 72, germinated time.
which could not be provided by the short branch chains, so the higher proportion of A chains (DP 6-12) may be due to the larger breakdown (Cheetham and Tao, 1998). The highest breakdown of GB12 indicates that the shear resistance and thermal stability of the glutinous brown rice starch gel in the present study decreased after germination, and the GB12 starch gel has the weakest thermal stability and shear resistance. The final viscosity and setback decreased after germination, which might be due to the degradation of starch structure during germination in which the gelatinized starch molecules have a low tendency of aggregation during cooling (Li et al., 2017). GB12 also has the highest value of setback during germination; it might indicate that GB12 starch is more difficult to retrogradation.

**Dynamic rheological properties**

Figure 5 shows the complex modulus of the starch gel of GB0, GB12, GB24, GB36, GB48, and GB72. In dynamic oscillatory measurements, the complex modulus ($G^*$) was redrawn as the logarithm of the temperature. In the first
stage, the $G^*$ increased, and the starch chains in the paste maintained a high fluidity above 50 °C, so the response to the oscillation strain was not obvious; In the second stage, with the further decrease of temperature, the increase of intermolecular association due to the poor mobility of amylopectin to oscillatory response becomes obvious. Therefore, the higher $G^*$ can be the evidence of the overall chain association in the second stage (Chung et al., 2008).

The temperature ($T_{\text{intercept}}$) at the intersection point between the first and the second stages of $G^*$ increase may express the onset temperature for chain association (Chung et al., 2008). After germination, $T_{\text{intercept}}$ increased, and the $T_{\text{intercept}}$ of GB36 is the lowest in all the germinated
glutinous brown rice starch. This indicates that germination leads to the chain association become harder. Among the second stage in the test, the rising slope of GB36 starch paste was the highest and the GB12 starch paste was the lowest; this indicates that GB36 starch is easy to get into chain association (retrogradation) but GB12 starch is difficult to retrogradation induced by cooling. GB36 has the highest proportion of long B chains, and the long B chains have more possible contact points which are easier to associate between chains (Chung et al., 2008).

Conclusions

This study evaluated the impact of different germination stages on the structural and rheological properties of the glutinous brown rice starch. The proportion of A chains was increased significantly; in contrast, the proportion of B chains decreased gradually. The total proportion of chain A to chain B reduced. Interestingly, we observed that the total proportion of B and B chains decreased before germination at 36 h, and rose again at 36 h, and then continued to decrease with the extension of germination time. The change of chain length distribution has a direct effect on the physicochemical properties of glutinous brown rice starch. Germination leads to a decrease in the degree of the relative crystallinity, gelatinisation enthalpy and pasting viscosities. In all the germinated glutinous brown rice starches, GB12 starch gel has the weakest thermal stability and its shear resistance is more difficult to retrogradation; the Tintercept of GB36 is the lowest and is easier to associate between chains (retrogradation). The effect of germination treatment on the fine structure and in vitro digestibility of glutinous brown rice starch has not been studied systematically. Further research is needed to provide theoretical basis for the development of glutinous brown rice starch.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Mohan BH, Malleshi NG, Koseki T (2010). Phyisco-chemical characteristics and non-starch polysaccharide contents of Indica and Japonica brown rice and their mals. LWT-Food Science and


**Full Length Research Paper**

**Competition indices and monetary advantage index of intercropping maize (Zea mays L.) with legumes under supplementary irrigation in Tselemti District, Northern Ethiopia**

Tefahun Mekuanint

Shire-Maytsebri Agricultural Research Center, Shire-Endasilase, Tigray, Ethiopia.

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An understanding of competitive and monetary indices such as land equivalent ratio (LER), land equivalent coefficient (LEC), relative crowding coefficient (K) and monetary advantage index (MAI) is critical in recommending cropping systems in a given area. To appreciate this, an experiment was conducted in Tselemti, Tigray region, Northern Ethiopia. Maize (Zea mays L.) was intercropped with Soybean and Mung bean in a 50:50 ratio under rainfed conditions and supplemented with irrigation in the 2016/17 season to determine the effect of leguminous competition on maize and the economic viability of the intercropping system over sole cropping. The experiment was laid in a split-plot design in three replications with intercropping taking the main plots and supplementary irrigation to sub-plots. The LER values were generally greater than one which indicated the yield advantages of intercropping over sole cropping. LEC was well above 25% and this means that intercropping was more productive. The highest value of LEC was recorded in wheat-lentil mixtures. The relative crowding coefficient (K) showed that the legumes were more dominant over maize. Although both maize-soybean and maize-mungbean mixtures showed economic advantage, as recorded by positive MAI, maize-soybean intercropping system proved more profitable under rainfed conditions whereas under supplementary irrigation, maize-Mungbean recorded a higher value of MAI. Conclusively, it was demonstrated that maize-soybean combinations were more advantageous in terms of yield and monetary advantage for smallholder farmers in Tselemti area who depend on rainfed farming.

**Key words:** Competition, mungbean, intercropping, supplementary irrigation, soybean, maize.

**INTRODUCTION**

Moisture stress negatively affects the physiological and agronomic growth of maize, resulting in significant yield reduction (Balla et al., 2008). However, the use of self-sustaining low input technologies has been suggested as...
a sustainable approach to build soil productivity of such areas, with minimum use of external inputs. Supplementary irrigation has also been reported to increase yields in drylands by more than 50% (Bello, 2008). Cereal-legume intercropping is among such practices recommended for soil restoration in Ethiopia (Coxhead and Oygard, 2008).

Intercropping is a multiple cropping system that combines the planting of two or more crops species simultaneously in the same field during a growing season (Mousavi and Eskandari, 2011). It has the capacity to fulfill several agro ecological goals such as enhancing the natural nutrient regulation (Chapagain, 2014), efficient use of resources, and weed suppresssion (Chapagain, 2014; Ghanbari et al., 2010) among others. In Ethiopia, intercropping forms part of the smallholder farming systems where maize (Zea mays L.) and sorghum (s. bicolor L.) dominate as main crops (Tarekegn and Zelalem, 2014).

Despite its numerous benefits, the practice is being abandoned for sole cropping since the current extension services and technologies in the country are promoting sole cropping. Hence in many parts of Ethiopia, farmers mostly harvest only once in a year on sole crop basis even in areas that receive sufficient rainfall (Yayeh et al., 2014b). Nevertheless, this does not provide sufficient food supply for the households and does not make efficient use of the limited resources such as rainfall and land.

However, management practices that emphasize the integration of maize with leguminous species could optimize the use of environmental resources, increase production where land area expansion is not possible and also enhances rich and diversified diet options. Yet, these benefits and interaction were not properly studied in the study area. Studies in other areas have shown that indices such as land equivalent ratio (LER) are useful to substantiate the resource utilization efficiency of intercropping system (Willey and Osiri, 1972), land equivalent coefficient (LEC) to measure the strength of the relationship (Adetiloye et al., 1983), relative crowding coefficient (K) to measure the relative species dominance of multiple cropping (De Wit, 1960), and monetary advantage index (MAI) to evaluate the economic benefits of intercropping over sole cropping (Willey, 1979).

Therefore, such indices should be taken into account in recommending cropping systems for a given area. Thus, the objectives of this paper were;

1) To determine the effect of competition among the two different leguminous species (soybean Glycine max (L.) Me rril) and Mungbean (Vigna radiata) in maize intercropping;
2) To study the economic viability of intercropping maize with soybean and mungbean compared to its sole cropping under supplementary irrigation (SI).

**MATERIALS AND METHODS**

**Description of the study area**

The field study was conducted at Tselemti wereda, which is found in North Western Tigray administration zone during the 2016/2017 main cropping season (about 13° 59’N, 38° 14’E at 1323 meters above sea level). It is located in the arid agro-ecology with a unimodal type of rainfall received around June. Agriculture is the main livelihood of the community in the study area. Known for their mixed farming system, the rural people depend on crop and livestock production in addition to agro forestry practices for their living. People are also engaged in traditional gold mining as a main off-farm income. Soil in the area is classified as clay (Table 1 and Figure 1).

**Experimental design and treatments**

Maize variety, obtained from Melkaasa Agricultural research center was intercropped with two legume species: Soybean and Mung bean in the ratio of 1:1 under rainfed and supplementary irrigation in a split-plot design with three replications. The main plot constituted the two intercropping combinations while supplementary irrigation was applied to the sub-plots. Pure stands of maize, soybean and mungbean as well as the solitary ratios of Maize-legume intercropping were planted. Sole maize was planted at a seeding rate of 125 kg ha⁻¹, sole soybean and mungbean at seeding rates of 65 and 30 kg ha⁻¹ respectively. Whereas for the intercropped treatment of maize, half of the recommended seeding rate was applied. Maize was drilled 75 cm between rows, while Soybean was drilled at a spacing of 60 cm and Mung bean was planted at a spacing of 10 x 40 cm. The space between the rows of maize and any legume rows was 20 cm. A basal fertilizer application of Di ammonium phosphate (DAP) (18% N, 46%P) at a rate of 100 kg ha⁻¹ and 50 kg ha⁻¹ urea (46% N) at planting, while the second half of urea was top-dressed at tillering stage. A 135 mm supplementary irrigation was applied to the irrigated sub-plots at booting stage to replenish soil moisture during the dry spells.

**Competition indices and monetary advantage index**

**Land equivalent ratio (LER)**

LER was used as the first criteria to demonstrate the advantages mixed cropping over the other among the different species (Willey,

<table>
<thead>
<tr>
<th>Sand (%)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>K ppm</th>
<th>Av.P ppm</th>
<th>Tot. N (%)</th>
<th>C (%)</th>
<th>EC (dSm⁻¹)</th>
<th>PH</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>42</td>
<td>33</td>
<td>130.3</td>
<td>1.2</td>
<td>0.1022</td>
<td>1.06</td>
<td>0.32</td>
<td>6.08</td>
</tr>
</tbody>
</table>


**Table 1. Chemical and physical characteristics of the soil of experiment.**


It shows the effectiveness of intercropping in resource utilization in the environment in comparison with monocropping (Mead and Willey, 1980). In other words, LER can be used to indicate complementarities among species in the intercrop (Yayeh et al., 2014b). A unitary value of LER is the reference value. LER value greater than one indicates that intercropping is advantageous over sole cropping in terms of growth and yield of both species. A value of LER less than one, indicates the negative effect of the interaction on the species in the mixture (Ofori and Stern, 1987; Yayeh et al., 2014b). Therefore, LER was calculated according to Willey and Osiru (1972), as;

\[
LER = LER \text{ Wheat (A)} + LER \text{ Legume (B)};
\]

where, \( LER \text{ wheat} = \left( \frac{Y_{A}}{Y_{A,S}} \right) \) and \( LER \text{ Legume} = \left( \frac{Y_{B}}{Y_{B,S}} \right) \)

Where:

\( Y_{A,I} \) and \( Y_{B,I} \) are yields of wheat and legume in the intercrop respectively while \( Y_{A,S} \) and \( Y_{B,S} \) are the sole crop yields of wheat and the legumes respectively.

**Land equivalent coefficient (LEC)**

The strength of the intercropping interaction was determined using land equivalent coefficient (LEC), also referred to as the productivity index (PC). LEC was used because it is a more superior index in evaluating crop mixture performance in terms of mixture productivity (Adetiloye et al., 1983). Thus, was calculated as;

\[
LEC = L_a \times L_b
\]

Where:

\( L_a = LER \) of main crop and \( L_b = LER \) of intercrop

coefficient (PC) is 25%, that is, a yield advantage is obtained if LEC value exceeds 0.25.

**Crowding coefficient (K)**

Crowding effect is also one of the indices used in computing the competition effect of intercropping. It gives a measure of the relative dominance of one species over the other in multiple cropping (Banik et al., 2006). Each of the species within an intercropping has its own relative crowding coefficient and the one with higher values are said to be more dominant (De Wit, 1960). It was calculated according to the formula below;

\[
K_{ab} = \frac{Y_{ab}}{Y_{a} - Y_{ab}} \quad \text{and} \quad K_{ba} = \frac{Y_{ba}}{Y_{b} - Y_{ba}}
\]

Where:

\( K_{ab} \) and \( K_{ba} \) are the relative crowding coefficient of wheat in legume and legume in maize respectively; \( Y_{a} \) and \( Y_{b} \) are yields of maize and legumes in monoculture; \( Y_{ab} \) is the yield of maize in poly culture with a legume and \( Y_{ba} \) to denote the yield of the legume in the intercrop. When the value of \( K \) is greater than 1, there is a yield advantage, when \( K \) is equal to 1, it indicates no yield advantage and \( K \) values less than one show a yield disadvantage of intercropping.

**Monetary advantage index (MAI)**

The economic feasibility of intercropping over sole cropping was calculated using the monetary advantage index (MAI). MAI is an important index in determining economic viability of intercropping. It was calculated according to Willey (1979) as;

\[
MAI = \frac{\text{value of combined intercrops}}{LER} \times (LER - 1)
\]
Table 2. Land equivalent ratio (LER) and Land equivalent coefficient (LEC) of maize-legume intercropping at Tselemti, Ethiopia in 2016/2017.

<table>
<thead>
<tr>
<th>Rainfed</th>
<th>Supplementary irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>LER</td>
</tr>
<tr>
<td>Maize</td>
<td>Legume</td>
</tr>
<tr>
<td>Maize + Soybean</td>
<td>1.06</td>
</tr>
<tr>
<td>Maize + Mungbean</td>
<td>0.78</td>
</tr>
</tbody>
</table>

The higher MAI value will indicate more profitable cropping system over the other (Muhammad et al., 2008). The value of the component crops were computed basing on the average market price in Tselemti area in Ethiopian Birr (ETB) after harvest time.

Data analysis

Data were statistically explored using the descriptive analysis of variance (ANOVA). Gen Stat version 14 was used for each of the indices (Payne, 2014) according to standard analysis of variance procedures (Gomez and Gomez, 1984), and least significant difference (LSD) test at 5% probability level using Duncan’s multiple range test was used to compare the treatment means.

RESULTS AND DISCUSSION

Competitive indices

Land equivalent ratio (LER) and land equivalent coefficient (LEC)

LER is an effective and widely used index for comparing intercropping systems due to different species growing on the same piece of land (Beets, 1982; Yayeh et al., 2014b). Intercropping maize with Soybean and Mung bean under rainfed and supplementary irrigation significantly (p < 0.05) affected LER.

In general, the partial LER for maize was lower in maize-legume mixtures than in sole wheat both in rainfed and with supplementary irrigation. Higher partial LERs (0.77 and 0.91) were registered under maize-soybean mixtures under rainfed and supplementary irrigation respectively (Table 2). Intercropping maize with Soybean gave higher values of total LER (1.83 and 2.38) respectively compared to maize-mungbean mixtures under rainfed and supplementary irrigation (Table 2). This indicates that 83% (0.83 ha) and 138% (1.38 ha) more land area in sole cropping system would produce the same yield as in the intercropping system of maize and soybean under rainfed and supplementary irrigation respectively.

Nevertheless, maize-mungbean also gave LER values greater than one under both water regimes, also indicating a yield advantage over sole cropping (Table 2). This also demonstrates that intercropping systems were more effective in utilization of environmental resources for growth and yield formation over sole cropping. Similar results were also reported by Yayeh et al. (2014a) who reported values of LER well above one in wheat-lupine and barley-lupine intercropping.

Likewise, Caballero et al. (1995) reported intercropping vetch with oat to be advantageous in terms of yield over sole cropping. According to Willey (1979), intercropping systems with constantly higher LERs well-above one are considered more resource-use efficient than mono crops. Muhammad et al. (2008) and Yadav and Yadav (2001) also reported yield advantage in crop mixtures than equivalent sole crops on the same land area. However, this varies with the species combination and seeding ratio.

High population of cereals have been reported to negatively affect the overall yield, hence resulting in LER values less than one. For instance, B. Yayeh et al. (2014a) reported LER values less than one in lupine-barley and lupine wheat intercropping in the ratios of 75:100 and 50:100 respectively. This was probably due to higher competitive ability of the cereals at higher populations. Matching duration of maturity between the component crops was also reported to reduce the value of LER to less than one in lupine-finger millet intercropping since they were assumed to have critical resource demands at the same time period (Yayeh et al., 2014a) (Table 2).

The study showed that the LEC of maize was significantly affected (p <0.005) by intercropping with soybean and mung bean, and LEC was generally greater than 25% in all the treatments (Table 2). Maize-Soybean intercropping demonstrated more productivity as was demonstrated by higher LEC values of 0.82 and 1.34 in rainfed and irrigated conditions respectively as compared to Maize-mungbean mixture (Table 2). Expectedly, supplementary irrigation recorded higher LEC than rainfed conditions as shown in the Table 2. The results aforementioned demonstrated that intercropping had yield advantage over sole cropping and maize-soybean combination was to be more productive both with rainfed and supplementary irrigation. Egbe (2010) also reported LEC values above 25% in maize intercropping systems.

Relative crowding coefficient (K)

Relative crowding effect was another coefficient used in the study and it is the relative dominance of one species over the other (Banik et al., 2006). The relative crowding
that MAI was positive in all the intercropping systems, respectively over the respective monocultures. This index however did not provide a more realistic comparison of yield advantage and was relatively indifferent to LER and LEC (Table 3).

### Economic advantage of intercropping

**Monetary advantage index (MAI)**

Most intercropping indices mainly give the agronomic and yield advantages of intercropping, and do not take into account the economic and absolute yield comparisons (Tamado and Mulatu, 2000; Yayeh et al., 2014b). Nevertheless it is necessary to perform some monetary evaluations to satisfactorily compare the value of the yield advantage (Willey, 1979).

The study demonstrated that intercropping wheat with legumes significantly affected the MAI ($p < 0.05$). It showed that MAI was positive in all the intercropping systems and higher above one (Table 4). This indicates that the intercropping systems were more economically feasible weighed compare to sole cropping. This conforms to similar results by Dutta et al. (1994) on maize-rapeseed combinations.

MAI was higher in maize-soybean in the absence of supplementary irrigation (ETBr 7.937.2). However, with application of supplementary irrigation, Maize – mungbean intercropping had higher values of MAI (ETBr 22,500) (Table 4). These results imply that it was more economically viable to intercrop maize with lentil under rainfed conditions in the study area, whereas Maize-mungbean intercrop demonstrated economic advantage under supplementary irrigation. This signifies unsuitability of mungbean in maize intercropping under rainfed conditions and entails that maize-soybean intercropping systems is more suitable for the rainfed farming systems.

<table>
<thead>
<tr>
<th>Table 3. The relative crowding coefficient (K) for mixtures of maize and legumes under rain fed and supplementary irrigation in Tselemti, Ethiopia in 2016/2017.</th>
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<tbody>
<tr>
<td><strong>Relative competition coefficient (K)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Rainfed</td>
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<tr>
<td>SSI</td>
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</table>

Kw: coefficient of wheat; Kl: coefficient of lentil; Kd: coefficient of dekoko; K: product of coefficient.

<table>
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<tr>
<th>Table 4. The MAI for maize-legume intercropping in Tselemti, Ethiopia.</th>
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<tbody>
<tr>
<td><strong>Treatment</strong></td>
</tr>
<tr>
<td><strong>Rainfed</strong></td>
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<tr>
<td>Maize + Soybean</td>
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<td>Maize + Mungbean</td>
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of the study area. These results followed a similar trend as the LER and LEC competitive indices (Table 2). It was reported by Dhima et al. (2007) that when LER and LEC values are higher, there is also economic advantage in terms of MAI. Intercropping lupine-wheat and lupine-finger millet also gave more economic returns compared to sole cropping (Yayeh et al., 2014a).

CONCLUSION AND RECOMMENDATIONS

LER was greater in both maize-soybean and maize-mungbean intercropping and as well, the LEC was greater than 25%. MAI was also positive showing that intercropping was more efficient in terms of resource utilization in the environment than sole cropping. Moreso, LER demonstrated that 24 and 83% more land in maize-mungbean and maize-soybean respectively would be required in sole cropping to produce the same yields as in intercropping under rainfed conditions. Therefore, intercropping would serve as a more sustainable way of improving soil productivity among the low-input farmers in Tselemti area and similar agro ecologies. It also suggests maize-soybean as the most economical combination for maize intercropping in the area. Besides, these leguminous are new crop to the study area but in short time accepted they use those for local consumption and market. Therefore, introducing intercropping to the areas gives more advantages to the farmers. However, this study considered only a single ratio of combination of maize and the legumes, and in only one location. We recommend that a similar study should be conducted using different seeding ratios and with different intercropping patterns in different agro-ecologies to come with conclusive recommendations. In addition, a cost-benefit analysis of the different intercropping combinations and patterns would lead to the most economically feasible combination and agronomic management to be recommended for the smallholder farmers in the area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES


Beets WC (1982). Multiple cropping and tropical farming systems (Gower Publishing Co.).


Chapagain T (2014). Intercropping wheat and barley with nitrogen fixing legume species in low input organic systems, Electronic Theses and Dissertations (ETDs) 2008+


Yadav RS, Yadav OP (2001). The performance of cultivars of pearl millet and cluster bean under sole cropping and intercropping
systems in arid zone conditions in India. Experimental Agriculture. 37(2):231-40.
