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IMPROVEMENT OF ENERGY AND NUTRIENT DENSITY OF SORGHUM-BASED COMPLEMENTARY FOODS USING GERMINATION

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ABSTRACT

In Ethiopia, commercially made complementary foods are not available and affordable for the majority of the poor. Complementary foods prepared traditionally from locally available raw materials (such as cereals) have high viscosity when reconstituted. This limits the total food intake by infants. The main objective of this study was to investigate the effect of germination on energy and nutrient density of sorghum-based complementary foods. Two varieties of sorghum (*Sorghum bicolor) (*L.) Moench) grains (varieties 76T1#23 and Meko) were collected, cleaned, soaked for 22 hours at room temperature (22±2^{0}C); germinated for 48 hours at the soaking temperature; dried at 55^{0}C for 24 hours, and milled into a fine homogeneous powder. Five complementary foods were formulated by using a blend of ungerminated to germinated sorghum flours in ratios of 100:0, 75:25, 50:50 and 25:75, 0:100, respectively. Germination increased significantly ($p<0.05$) contents of crude protein from 12.25% and 10.44% to 12.65% and 10.87% for varieties 76T1#23 and Meko, respectively. Similarly, the respective contents of total phosphorus, iron, zinc and calcium (mg/100g) were significantly ($p<0.05$) increased from 208.42, 8.21, 1.86 and 17.09 to 223.26, 11.99, 2.01 and 25.93 for variety 76T1#23 and from 183.04, 7.19, 1.78 and 20.99 to 192.91, 10.98, 1.89 and 29.62 for variety Meko. In contrast, germination decreased viscosity values (cP) (at five percent dry matter concentrations) from 2888.78 and 2988.43 to 1147.11 and 1148.20 for varieties 76T1#23 and Meko, respectively and at 15% dry matter concentrations from 8684.74 and 8791.98 to 2376.17 and 2416.24 for variety 76T1#23 and Meko, respectively. Blending of ungerminated with germinated sorghum flour also decreased viscosity values significantly. Panelists preferred gruels prepared from 100% ungerminated sorghum flour followed by gruels prepared from a blend of 75% ungerminated and 25% germinated sorghum flours. Gruels prepared from 100% germinated sorghum flour were least preferred. Hence, germination appeared to be a promising food processing method to improve energy and nutrient density and decrease viscosity values of complementary foods.

Key words: Complementary food, Germination, Nutrient density

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INTRODUCTION

Malnutrition affects physical growth, morbidity, mortality, cognitive development, reproduction, and physical work capacity [1]. Malnutrition and infectious diseases are the most widespread problems affecting infants and young children in developing countries [2, 3]. Adequate nutrition is essential for adequate growth and cognitive development of infants and young children and to resist and fight against infections [3, 4]. Breast milk is a sole and sufficient source of nutrition during the first six months of infant life [2-5]. Breast milk contains all the nutrients and immunological factors infants require to maintain optimal health and growth [5]. Towards the middle of the first year, breast milk becomes insufficient to support growing infants [2-5]. Therefore, nutritious complementary foods need to be introduced. Inadequate supplementary feeding of infants is an important factor in the high incidence of child malnutrition. Development of complementary foods is guided by nutritional value, acceptability, availability and affordability of raw materials, and simplicity of food processing technologies and equipment [6]. Complementary foods in developing countries are mainly made from starchy staples, which when cooked with water, become viscous and bulky with low energy and nutrient density [7].

The most serious nutritional deficiency in infants and young children is protein-energy malnutrition (PEM), which contributes to more than 50% of childhood mortality in developing countries [8, 9]. Infant malnutrition may be due to low energy and nutrient density that might be due to high viscosity and or undesirable sensory properties of complementary foods [7, 10]. Infant malnutrition due to nutritionally inadequate diets is one of the major concerns in Ethiopia. Children in rural Ethiopia are especially prone to nutrient deficiencies as they eat from the family dish, which is predominantly plant-based [11].

In Ethiopia, commercially made complementary foods are not available especially in the rural part of the country and if available, not affordable by the majority of the poor. Therefore, there is a need for low-cost complementary foods which can be prepared at community kitchens from locally available raw materials using simple technologies and equipment. This study reports the effect of germination on energy and nutrient density, viscosity, sensory attributes and acceptability of sorghum-based complementary foods.

MATERIALS AND METHODS

Sample collection

Two varieties of sorghum (*Sorghum bicolor (*L.) Moench) grains (varieties 76T1#23 and Meko) were collected for this study. Variety 76T1#23 was purchased from the Ethiopian Seeds Enterprise (ESE), Arsi Basic Seeds Storage and Preparation Center, Asella town, Arsi district, Ethiopia and variety Meko was obtained from Agricultural Research Institute of Ethiopia (EARI), Melkassa Agricultural Research Center (MARC), Awash Melkassa, Ethiopia.

Sorghum flour preparation

Sorghum grain samples were cleaned to remove stones, dust and light materials, glumes, stalks, and broken, undersized and immature grains. Cleaning was done by winnowing and hand sorting. The cleaned sorghum grains were divided into two portions. The first portion was not subjected to any treatment (served as control). The second portion was washed three times with deionized water and soaked in excess water for 22 hours at room temperature (22 ± 2^0C). The steeping water was drained off and the soaked sorghum grains were washed twice using deionized water. The soaked sorghum seeds were germinated for 48 hours at the soaking temperature and watered 2-3 times a day to enhance the germination process [12]. After germination, the sorghum seeds were washed using running deionized water and dried in a drying oven (Memmert, Germany) at 55^0C for 24 hours. The ungerminated sorghum grains were also dried in a drying oven at 55^0C for two hours to facilitate the milling process [13, 14].

The dried sorghum seeds, both ungerminated and germinated, were separately milled to a fine homogeneous powder using a Cyclotec sample mill (Tecator, Hoganas, Sweden) then passed through a 1.18 mm aperture size laboratory test sieve (Endecotts Ltd., London, England). The milled samples were then packed in airtight polyethylene plastic bags and stored at room temperature until needed.

Complementary food formulation

Using germinated and ungerminated sorghum flours, five complementary foods were formulated as shown in Table 1. The blending proportions of the five complementary foods were in the ratios of 100:0; 75:25; 50:50; 25:75 and 0:100 (w/w) of ungerminated to germinated sorghum flour (Table 1). These flours were thoroughly mixed, packaged and kept at ambient temperature until needed for analysis.

Chemical analyses

Proximate composition of the formulated complementary foods was determined by an AOAC method [15]. Crude protein content was determined (Nx6.25) using Kjeldahl apparatus (Kjeltec 2300 Analyzer unit, Foss Tecator AB, Hoganas, Sweden) [16]. For mineral analysis, a fresh sample (ca. 2.5 g) was ashed at 550^0C for six hours in a muffle furnace (Carbolite, Aston Lane, Hope, Sheffield, England, UK). When ashing was incomplete, several drops of concentrated nitric acid were added and the samples were re-ashed for three more hours at 550^0C. The ashed samples were dissolved in five ml 6N HCl and diluted to 50 ml with deionized water. The concentrations of iron, zinc and calcium were determined in an aliquot using an atomic absorption spectrophotometer (Varian SpectrAA-20 Plus, Varian Australia Pty., Ltd., Australia). For the determination of calcium, lanthanum chloride (10% w/v) was added to both standards and samples to suppress interference from phosphorus [17]. The same digest was used to determine total phosphorus [18].

Sensory evaluation

Gruels of the five formulated complementary foods were prepared by mixing 15 g of sorghum flour with 100 ml water and cooked for 25 minutes at 92^0C. Panelists were selected from the staff of Food Science and Nutrition Research Directorate, Ethiopian Health and Nutrition Research Institute (EHNRI), Addis Ababa, Ethiopia. The panelists were instructed about the purpose and objective of the test, and those chosen were interested and willing to serve, available during the sensory evaluation period and apparently healthy. The panel members were assigned individually to well-illuminated laboratory booths and the gruels prepared were served at 40^0C in white and transparent glass cups coded with random three digits. The panelists were instructed to rank the gruels on the basis of appearance (color), taste, odor and texture (mouth feel) using a nine point hedonic scale, (where 1 = dislike extremely and 9 = like extremely). Overall acceptability of the gruels was also rated on the same scale with 9 = extremely acceptable and 1 = extremely unacceptable [19, 20].

Viscosity determination

Gruels of the five formulated complementary foods were prepared at two concentrations in glass beakers by mixing five gram and 15 g of sorghum flour separately in 100 ml water and cooked at 92^0C for 25 minutes. The gruels were then placed in a water bath maintained at 40^0C. The viscosity values (in centipoises, cP) of each formulated complementary food were measured at each dry matter concentration separately at 40^0C using a Brookfield Viscometer (Model DVII Rheometer V2.0 RV; Middleboro, Massachusetts, USA) and spindle number 52 at a shear rate of six revolutions per minute [13, 20].

Data management and statistical analysis

Each determination was carried out in triplicate and results were reported as average values (mean ± standard deviation). Data were analyzed by one-way analysis of variance (ANOVA) using SPSS Version 15. Differences between treatments were determined by the Fisher's Least Significant Difference (LSD) method. Statistical significance was set at $p<0.05$.

RESULTS

Proximate composition

For both varieties, germination increased significantly ($p<0.05$) the crude protein and fiber content of sorghum flour. In contrast, the ungerminated sorghum flour of both varieties contained higher crude fat, moisture and total ash content compared to germinated sorghum flour. The moisture content of sorghum flour samples investigated in this study was below 10%. For both varieties, the blending of germinated with ungerminated flour was also found to increase crude protein and fiber level compared to ungerminated flour alone, while crude fat, moisture and total ash content decreased (Tables 2 and 3).

Mineral content

Germination was found to increase significantly ($p<0.05$) levels of iron, zinc, calcium and phosphorus. Blending of germinated sorghum flour with ungerminated flour also increased iron, zinc, calcium and phosphorus content (Tables 4 and 5).

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Viscosity

At five percent and 15% dry matter concentrations, viscosity values (in centipoises, cP) were highest for gruels prepared from 100% ungerminated sorghum flour, while gruels prepared from 100% germinated sorghum flour gave lowest viscosity values. Viscosity values of gruels of formulated complementary foods decreased during blending of increased proportions of germinated sorghum flour with ungerminated sorghum flour. Most of the impact in viscosity was recorded with the addition of only 25% germinated flour (Tables 6 and 7).

Sensory characteristics

The appearance (color), taste, odor, texture (moth feel) and overall acceptability of gruels prepared from 100% ungerminated sorghum flour were most preferred by the panelists followed by gruels made from a blend of 25% germinated and 75% ungerminated sorghum flour. Gruels prepared from 100% germinated sorghum flour were least preferred. In general, the higher the germinated flour content, the lower the score. However, the odor of the gruel made with 25% germinated sorghum flour was rated highest and its overall acceptability was similar to that of that made from 100% ungerminated flour (Table 8).

DISCUSSION

Low energy and nutrient density in complementary foods has been pointed out as a major cause of poor growth and undernutrition among infants and young children in developing countries [20]. Enrichment of sorghum-based complementary foods using germination significantly improved ($p \leq 0.05$) their energy and nutrient density.

Ungerminated sorghum flour samples investigated in the present study contained 12.25% and 10.44% of protein and 3.34% and 3.32% of fat contents, which were comparable to values reported elsewhere [21]. Germination increased protein contents of sorghum flour (Tables 2 and 3). Similar observations were made during germination of low-tannin sorghum grains [22] and preparation of instant *fura* from germinated pearl millet flours [12]. The observed increase in protein content of sorghum flour resulting from germination might be due to dry matter loss during germination as evidenced by decreased ash content (Tables 2 and 3). It might also be attributed to a net synthesis of enzymatic protein by germinating seeds [12, 14].

In the present study, germination significantly ($p<0.05$) decreased crude fat content of sorghum flours (Tables 2 and 3), which was in agreement with results of previous investigation [12]. Similar observations that germination reduced crude fat content of maize from 2.41% to 1.52% have been reported [7]. The observed decrease in fat content of sorghum flour during germination might be attributed to the increased activities of the lipolytic enzymes during germination, which hydrolyze fats to fatty acids and glycerol. The simpler products could be used for synthesis of carbohydrate and protein as evidenced by the increase in protein and carbohydrate content during germination (Tables 2 and 3) or used as a source of energy for developing embryo [7, 12].

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Germination decreased the moisture and total ash contents of sorghum flours significantly ($p<0.05$) (Tables 2 and 3), which is consistent with values reported for pearl millet and germinated maize [7]. The level of ash in food is an important nutritional indicator of mineral density and also a quality parameter of contamination. These minerals may include calcium, potassium, phosphorus, iron, sodium, zinc, magnesium and others at varying amounts. The observed decrease in ash content of sorghum flour samples during germination might be due to leaching of minerals during steeping and washing [7].

The moisture contents of all sorghum flour samples investigated in this study were below 10% (Tables 2 and 3). Such low moisture content of flours prevents microbial activity and extends the shelf life of the product [7, 23]. The fat content of sorghum flour decreased during germination, which might help to extend the shelf-life of the flour since food products with low values of fat have better shelf-life than similar products with high fat content [12]. In contrast, food products containing high fat are susceptible to both hydrolytic and oxidative or enzymatic rancidity responsible for both the general acceptability and storage stability of the product [23]. These results indicated that germination can also extend the shelf-life of food products.

In the current study, germination increased iron, zinc, calcium and phosphorus content of sorghum flour significantly ($p<0.05$) (Tables 4 and 5). This was consistent with results reported earlier [13], that the levels of certain minerals increased considerably in germinated flours. Similarly, a twofold increase in iron levels of sprouted hungry rice (*acha*) was also observed [12]. The observed increase in mineral contents (iron, zinc, calcium and phosphorus) of sorghum flour during germination might be due to losses of water-soluble constituents during steeping and washing [24].

Of the many chemical changes that occur during germination, the conversion of starch by α-amylase enzymes into dextrin and maltose is the one that has the greatest effect on viscosity [13, 25]. In the present study, viscosities of gruels prepared at five percent dry matter concentration (w/v) were within the range 1000-3000 cP, suggested to be suitable for infants and young children [26]. However, at this concentration the energy and nutrient density of gruels may still be too low to meet the energy and nutrient requirements of infants.

At 15% dry matter concentration (w/v), viscosity values of gruels from ungerminated sorghum flour (8684.74 cP and 8791.98, for the two varieties) were greater than 3000 cP. These gruels need to be diluted with water to make them suitable in viscosity for infant feeding. Germinated sorghum flour at 15% dry matter concentration gave viscosity values of 2376.17 cP and 2416.2419 cP, for the two varieties. This result indicated that complementary foods from germinated sorghum flours could be prepared at a higher solids concentration, 15% (w/v), without exceeding the upper viscosity limit (3000 cP). In this way the nutrients get concentrated in the formulation, which is beneficial.

Germination is a valuable process for the preparation of complementary foods with low paste viscosity and high energy and nutrient density [9, 21, 23], which is in agreement with results of the present investigation. Germination increased the energy and nutrient density of the formulated complementary foods by about 3-fold compared to ungerminated sorghum flour, which was comparable with results reported in previous study [25, 27].

Blending of germinated sorghum flour with ungerminated flour significantly ($p<0.05$) reduced viscosity values of the formulated complementary foods. This was consistent with results reported elsewhere [26, 28, 29]. With low viscosity, infants can easily consume more food due to added solid to the mixture. This will no doubt increase the nutrient density of the gruels, which is highly beneficial to the infants.

The observed reduction of viscosity of gruels during germination might be due to starch degradation by the action of α-amylases developed and or activated during the germination process [13, 30]. The enzyme α-amylase breaks down the starch molecules of the sorghum grain to dextrin and eventually to maltose and glucose.

Gruels from ungerminated sorghum flour were white while others were dark brown. The color of the gruels was disliked when the amount of germinated sorghum flour in the blend increased. The results obtained in this investigation were consistent with findings reported previously [7], which stated that the most preferred porridge was the most white in color, while the least preferred was the creamiest in color. The change in white color of gruels prepared from germinated sorghum flour was probably due to formation of brown pigments (melanoidins) through a Maillard reaction when the starch reacted with proteins probably during oven drying following germination. The presence of sugars from starch hydrolysis might also lead to color changes in the presence of proteins upon exposure to high temperature as reported by other researchers [7]. Gruels prepared from germinated sorghum flour were slightly dark brown, had bitter taste and strong malt flavor compared to gruels prepared from ungerminated sorghum flour [26].

CONCLUSION

The use of germinated sorghum flour in the formulation of complementary foods provides gruels of low viscosity and high energy and nutrient density, therefore, potentially increasing food intake. Utilization of simple utensils makes the germination process suitable for low-income families living in rural areas in developing countries.

Increased nutrient density and dry matter intake can also be obtained by blending germinated sorghum flour with ungerminated flour. Complementary food gruels containing ungerminated and germinated sorghum flour in ratios of 75:25, respectively, optimized the energy and nutrient density, viscosity values, sensory attributes and acceptability. This blend, therefore, has great potential as a complementary food in resource-poor, technologically underdeveloped countries.

Hence, germination is a promising food processing method for complementary food preparation, especially in developing countries.

Based on the present findings, formulating complementary foods using a blend of ungerminated with germinated sorghum flour in the ratios of 75:25, respectively, might be a viable option, because germinated flour needs to be prepared less often.

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Table 1: Blending proportions of complementary foods

Sample code	Blend proportion (%)	
	Ungerminated sorghum flour	germinated sorghum flour
100% ungerminated (control)	100	0
75% ungerminated	75	25
50% ungerminated	50	50
25% ungerminated	25	75
100% germinated	0	100

Table 2: Proximate compositions of sorghum flour samples (mean±SD) (variety 76T1#23)

Sample Code	Protein (%)	Fat (%)	Fiber (%)	Moisture (%)	Ash (%)	CHO* (%)	Energy (kcal/100g)
100% ungerminated	12.25 ± 0.1^{a}	3.37 ± 0.0^{a}	2.33 ± 0.1^{a}	8.05 ± 0.4^{a}	1.37 ± 0.1^{a}	72.63	369.85
75% ungerminated	12.43 ± 0.9^{b}	3.34 ± 0.4^{a}	2.67 ± 0.8^{b}	7.53 ± 0.9^{b}	1.30 ± 0.1^{b}	72.73	370.70
50% ungerminated	12.54 ± 0.1^{c}	3.30 ± 0.3^{b}	2.69 ± 0.2^{b}	7.46 ± 0.9^{c}	1.27 ± 0.0^{cb}	72.74	370.82
25% ungerminated	12.59 ± 0.8^{c}	3.27 ± 0.3^{b}	2.79 ± 0.6^{c}	7.39 ± 0.5^{d}	1.25 ± 0.1^{c}	72.71	370.63
100% germinated	12.65 ± 1.0^{d}	3.21 ± 0.5^{c}	2.81 ± 0.3^{c}	6.98 ± 0.3^{e}	1.24 ± 0.1^{c}	73.11	371.93

*CHO=carbohydrate excluding crude fiber
Values within the same column with different superscript letters are significantly different from each other ($p<0.05$)

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Table 3: Proximate compositions of sorghum flour samples (mean±SD) (variety Meko)

Sample Code	Protein (%)	Fat (%)	Fiber (%)	Moisture (%)	Ash (%)	CHO* (%)	Energy (kcal/100g)
100% ungerminated	10.44±0.9[a]	3.67±0.4[a]	3.32±1.0[a]	8.35±1.3[a]	1.55±1.1[a]	72.67	365.47
75% ungerminated	10.76±1.1[b]	3.43±0.9[b]	3.59±.9[b]	7.75±1.0[b]	1.49±0.9[b]	72.98	365.83
50% ungerminated	10.79±0.8[c]	3.42±0.3[c]	3.65±0.5[c]	7.57±1.1[c]	1.48±0.6[bc]	73.09	366.30
25% ungerminated	10.81±1.3[d]	3.38±0.9[d]	3.66±0.8[c]	7.55±0.9[cd]	1.47±0.6[c]	73.13	366.18
100% germinated	10.87±0.6[e]	3.38±1.2[d]	3.67±0.9[c]	7.53±0.8[d]	1.42±0.8[d]	73.13	366.42

*CHO=carbohydrate excluding crude fiber
Values within the same column with different superscript letters are significantly different from each other ($p<0.05$)

Table 4: Minerals contents of sorghum flour samples (mean±SD), (variety 76T1#23)

Sample Code	Iron (mg/100g)	Zinc (mg/100g)	Calcium (mg/100g)	Phosphorus (mg/100g)
100% ungerminated	8.21±0.1[a]	1.86±0.1[a]	17.09±0.3[a]	208.42±0.1[a]
75% ungerminated	9.71±0.6[b]	1.93±0.2[b]	20.00±0.8[b]	213.52±4.7[b]
50% ungerminated	10.53±0.3[c]	1.95±0.1[bc]	22.84±1.3[c]	218.13±0.7[c]
25% ungerminated	11.07±0.4[d]	1.97±0.6[c]	23.73±0.9	219.29±0.3[d]
100% germinated	11.99±0.8[e]	2.01±0.2[d]	25.94±0.6[e]	222.38±1.0[d]

Values within the same column with different superscript letters are significantly different from each other ($p<0.05$)

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Table 5: Minerals contents of sorghum flour samples (mean±SD), (variety Meko)

Sample Code	Iron (mg/100g)	Zinc (mg/100g)	Calcium (mg/100g)	Phosphorus (mg/100g)
100% ungerminated	7.19±1.2[a]	1.78±0.9[a]	20.99±1.5[a]	183.04±0.1[a]
75% ungerminated	8.45±1.0[b]	1.83±1.2[b]	24.47±1.2[b]	184.51±1.7[b]
50% ungerminated	9.92±0.9[c]	1.85±1.1[b]	26.65±0.9[c]	186.62±0.7[c]
25% ungerminated	10.60±0.8[d]	1.89±1.5[c]	28.70±1.3[d]	188.34±1.3[d]
100% germinated	10.98±1.3[e]	1.89±0.9[c]	29.62±1.6[e]	192.91±1.0[e]

Values within the same column with different superscript letters are significantly different from each other ($p<0.05$)

Table 6: Viscosity values of gruels prepared from sorghum flour (mean±SD) (variety 76T1#23)

Sample code	Viscosity (cP) at 5% DM*	Viscosity (cP) at 15% DM*
100% ungerminated	2888.78±7.5[a]	8684.74±5.1[a]
75% ungerminated	1289.76±4.5[b]	2964.14±4.5[b]
50% ungerminated	1274.73±3.2[c]	2838.08±3.9[c]
25% ungerminated	1239.70±7.6[d]	2717.03±4.6[d]
100% germinated	1147.11±8.9[e]	2376.17±2.7[e]

*DM=dry matter concentration
Values within the same column with different superscript letters are significantly different from each other ($p<0.05$)

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Table 7: Viscosity values of gruels prepared from sorghum flour (mean±SD) (variety Meko)

Sample code	Viscosity (cP) at 5% DM*	Viscosity (cP) at 15% DM*
100% ungerminated	2988.43±5.3[a]	8791.98±4.7[a]
75% ungerminated	1258.49±3.7[b]	2796.90±3.9[b]
50% ungerminated	1223.73±4.8[c]	2671.35±4.1[c]
25% ungerminated	1186.96±5.6[d]	2543.80±7.8[d]
100% germinated	1148.20±5.3[e]	2416.24±2.5[e]

*DM=dry matter concentration
Values within the same column with different superscript letters are significantly different from each other ($p<0.05$)

Table 8: Scores of sensory characteristics and overall acceptability of gruels

Sample code	Appearance (color)	Taste	Odor	Texture (mouth feel)	Acceptability
100% ungerminated	6.92[a]	6.73[a]	6.34[a]	7.02[a]	6.76[a]
75% ungerminated	6.65[b]	5.60[b]	6.51[b]	5.72[b]	6.78[a]
50% ungerminated	5.59[c]	5.19[c]	5.56[c]	5.20[c]	6.39[b]
25% ungerminated	5.37[d]	4.56[d]	5.79[d]	4.27[d]	5.27[c]
100% germinated	3.27[e]	3.41[e]	3.78[e]	2.94[e]	3.53[d]

Values within the same column with different superscript letters are significantly different from each other (at $p<0.05$)

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