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EFFECTS OF SOAKING AND GERMINATION TIME ON THE ENGINEERING PROPERTIES OF FINGER MILLET (*ELEUSINE CORACANA*)

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ABSTRACT

The effect of germination time on malting loss and engineering properties namely: 1000 kernel weight, bulk density, true density, porosity, length, width, thickness, geometric mean diameter, arithmetic mean diameter, sphericity, surface area, sample volume and angle of repose were studied. Increase in germination time increased malting loss up to 35.27% after 96 hours of germination. Reduction in thousand kernel weight, bulk density and true density was 35.8%, 25.4% and 20.18%, respectively after 96 hours of germination. Porosity of grains was decreased while length increased with increase in germination time up to 72 hours of germination. Width and thickness showed an increase up to 36 hours and 24 hour of germination, respectively, followed by a linear decrease. A similar trend was observed in geometric and arithmetic mean diameter, sphericity, surface area and sample volume of grains. Angle of repose increased from 24.93^{o} to 32.81^{o} after 72 hours of germination followed by a linear decrease.

1.Introduction

Agriculture is facing various problems like deepening of water bed level and expansion in drylands (CGIAR, 2017). The changing climate conditions along with nutrient deficient soils are not favourable for cultivation of wheat and rice and worldwide agriculturists are searching for a suitable alternative to these cereals. In view of these constraints, millets have attracted the attention of agriculturists and food technologists, as these are rich in nutrients, can grow on soils with low fertility, require less irrigation and are resistant to insects and pests (Singh and Srivastava, 2006; Devi *et al.,* 2014). Owing to this, the year 2018 was declared as the International year of millets. In this connection, finger millet, one of the highly produced millet in India with excellent nutrient quality, projects a tremendous scope in designing foods for developed as well as developing world. It possesses good drought tolerance, has ability to tolerate salinity and can be grown in soils with pH range of 5.0 to 8.2 (Upadhyaya, 2011). Finger millet is most nutritious among the major cereal grains. It is rich in high quality protein (Admassu *et al.,* 2009) which contains all the essential amino acids (Mbithi-Mwikya *et al.,* 2000). The content of free sugars has been reported in the range of 0.47 to 1.5% (Nirmala *et al.,* 2000; Kumar, 2013) which along with high dietary fibre (12%) (Saleh *et al.,* 2013) make it a low glycemic food. It is also gluten free (Admassu *et al.,* 2009; Singh and Raghuvanshi, 2012; Devi *et al.,* 2014).The cholesterol lowering and cancer reducing studies of finger millet has also been reported (Burton and Froston, 1966;

Burton *et al.,* 1972). Owing to its health benefits worldwide researches are being conducted to develop value added health products from finger millet (Verma and Patel, 2013; Shukla and Srivastva, 2014). However, the high amount of phytates, phenols, tannins and enzymes in finger millet inhibits maximum absorption of its nutrients which decreases its food value. Many processing methods like soaking, germination, roasting, and fermentation have been recommended by various researchers to reduce the anti-nutrients of finger millet (Tatala *et al.,* 2007; Venkateswaran and Vijyalakshmi, 2010). Germination is believed to be the most promising methods to reduce anti-nutrients and change the functionality and digestibility of grains (Pawar *et al.,* 2007; Onyango *et al.,* 2013). The germinated grains can be dried to a safer moisture limit and can be stored for further processing.

Effects of soaking and germination on the chemical composition of finger millet has been studied by many researchers (Nirmala *et al.*, 2000; Tatala *et al.*, 2007; Venkateswaran and Vijyalakshmi, 2010) but the effect of germination time on the engineering properties of finger millet is still unexplored. Gravimetric properties like bulk density, true density and porosity is important to determine the drying rate and aeration properties as these properties affect the rate of air flow (Sobukola *et al.*, 2013). Knowledge of the dimensional properties like length, width, thickness, geometric mean diameter and arithmetic mean diameter are important in separation of undesirable materials like unwanted roots and shoots from malted grains. Surface and frictional properties like sphericity and angle of repose plays an important role in designing material handling equipments like hoppers, conveyor belts and storage structures like silos (Balasubramanian and Vishwanathan, 2010). Therefore, the present study was designed to study the effect of germination time on engineering properties of finger millet This information can help food researchers and processors to exploit the usage of malted finger millet grains in development of value added products.

2.Materials and methods

2.1. Procurement of raw material

Finger millet (*Eleusine corcana*) grains of variety VL Manduaa-315 were procured from Vivekananda Parvatiya Krishi Anusandhanshala Almora U.P. The grains were cleaned by winnowing to separate residual particles (husks, chaff and un-matured seeds). Cleaned grains were then collected, dried in a tray drier (Narang Scientific Works Limited) to the final moisture content of 8±0.5 %, and stored for further use. The moisture content of the samples was determined by oven drying method at 130 °C for 2 hours (AOAC, 2010).

2.2. Malting

Malting is a three step process consisting of soaking, germination and drying. In the present study clean grains were soaked overnight in potable water, excess water was removed, and were spread in thin layer in a seed germinator maintained at 25±2 ºC and 95% relative humidity. Germination was carried for a time interval ranging from 12 hours to 96 hours. After every 12 hours interval samples were removed, dried in a hot air oven (50±2°C) to moisture content of 8±0.5 %, de-vegetated and were stored for further analysis.

2.2.1 Malting loss

Malting loss is defined as the weight of grain lost during the malting process (Nirmala *et al.,* 2000). Malting loss was calculated by using the following formula

Total malting loss (%) = Weight of grains before malting - Weight of grains after malting × 100/ Weight of grains before malting (Eq.1)

2.3. Gravimetric properties

2.3.1. Thousand kernels weight

Thousand kernels weight was measured by selecting 1000 grains randomly from pre-cleaned grains. The selected kernels were weighed on a digital electronic balance. The test was performed five times and the mean value was calculated (Mariotti *et al.*, 2006).

2.3.2. Bulk density

Bulk density was measured using calibrated measuring cylinder of 1000 ml capacity. The cylinder was filled to appropriate height with the clean grains (Mariotti *et al.,* 2006). Bulk density was calculated by taking ratio of the sample weight and volume of the cylinder and was represented as Kg/m^3. Average of 5 replications was taken.

Bulk density = Sample weight/volume

2.3.3.True density

The true density was determined by the liquid displacement method. 10 grams of cleaned grains were immersed in a 50 ml measuring cylinder containing 20 ml of toulene. The amount of oil displacement was recorded and true density was calculated using the formula:

True density = Weight of grains/volume of displaced toluene

2.3.4.Porosity

Porosity is the measure of fraction in the bulk grain which is not occupied by the grain (Ramashia *et al.,* 2017). It is calculated by putting the values of true density and bulk density in the under given formula.

Porosity (Ɛ) = [(Pt-Pb)/Pt]*100 (Eq.2)

Where, Pt = True density, Pb- Bulk density

2.4. Dimensional properties

The principal dimensions of length, width and thickness were measured with the help of a projector with a 10X scale by selecting 10 random grains for each treatment, drawing images on a white paper, measuring dimensions and finally reducing them to original size by dividing with 10. Further geometric mean diameter, arithmetic mean diameter, sphericity, surface area, and sample volume were calculated by using formulas given by various researchers (Sharma *et al.,* 1985; Sreenarayanan *et al.,* 1985; Jain and Bal, 1997; Ledbetter and Sisterson, 2010; Onyango *et al.,* 2013; Ramashia *et al.,* 2017).

Geometric mean diameter = $(LWT)^{1/3}$ (Eq.3)

Arithmetic mean diameter = $(L+W+T)^{1/3}$ (Eq.4)

Sphericity = $[(LWT)^{1/3/L}]100$ (Eq.5)

Surface area = $(\pi BL^2)/(2L-B)$ (Eq.6)

Sample volume = $(\pi B^2L^2)/[6(2L-B)]$ (Eq.7)

Where, L= Length, W= Width, T= Thickness, B = $(WT)^{0.5}$ (Eq.8)

2.5. Angle of repose

The angle of repose was determined on a plywood surface with the help of a cylinder opened at both the ends i.e. top and bottom end. The cylinder was kept on the plywood surface and was filled up to top with cleaned finger millet grains. The cylinder was then lifted up gradually from the surface until a conical heap was formed. Angle of repose was calculated from the height and base radius of the heap formed (Owolarafe *et al.,* 2007).

Angle of repose (θ) = $\tan^{-1}$ 2h/d (Eq.9)

3.Results and discussion

3.1. Malting loss and gravimetric properties

Malting loss has been defined as the loss of grain mass during germination. The effect of germination time on the malting loss and gravimetric properties has been shown in Table 1.

With increase in germination time malting loss increased gradually from 0 to 35.27 % after 96 hours of germination which might be due to the hydrolysis of stored complex carbohydrates into simple sugars (Handa *et al.,* 2017) and the utilization of these sugars in the embryonic growth (Vidal-Valverde *et al.,* 2002). Similar results have been reported by other researchers. Kumar (2013) reported a malting loss of 30 % in local finger millet variety of Himachal Pradesh while Nirmala *et al.,* (2000) reported a malting loss of 32 % in Indaf-15 variety. Malting loss had a direct significant ($P \leq 0.05$) relation with gravimetric properties (fig. 1) and an increase in malting loss resulted in decreased values for thousand kernel weight, bulk density and true density and same has been observed in correlation analysis of data (Table 4). Density is the measure of the mass per unit volume and is important to design the storage structures and handling equipments. Density is dependent on surface properties like surface area and sample volume and an increase in these parameters resulted in decrease in density. Porosity was reduced significantly ($P \leq 0.05$) in the initial 72 hours of germination which might have been due to the migration of nutrients to surface and filling of pores during soaking. The reason for increase in porosity after 72 hours of germination might be due to the shrinking of grains and formation of cracks on the skin. A decrease in porosity has been also reported by Kumar and Prasad, on parboiling of rice (Kumar and Prasad, 2013). Porosity and density also affect the rate of moisture removal during drying (Bai *et al.*, 2012). The grains with low porosity have a greater resistance to the removal of moisture and hence require high power aeration fans.

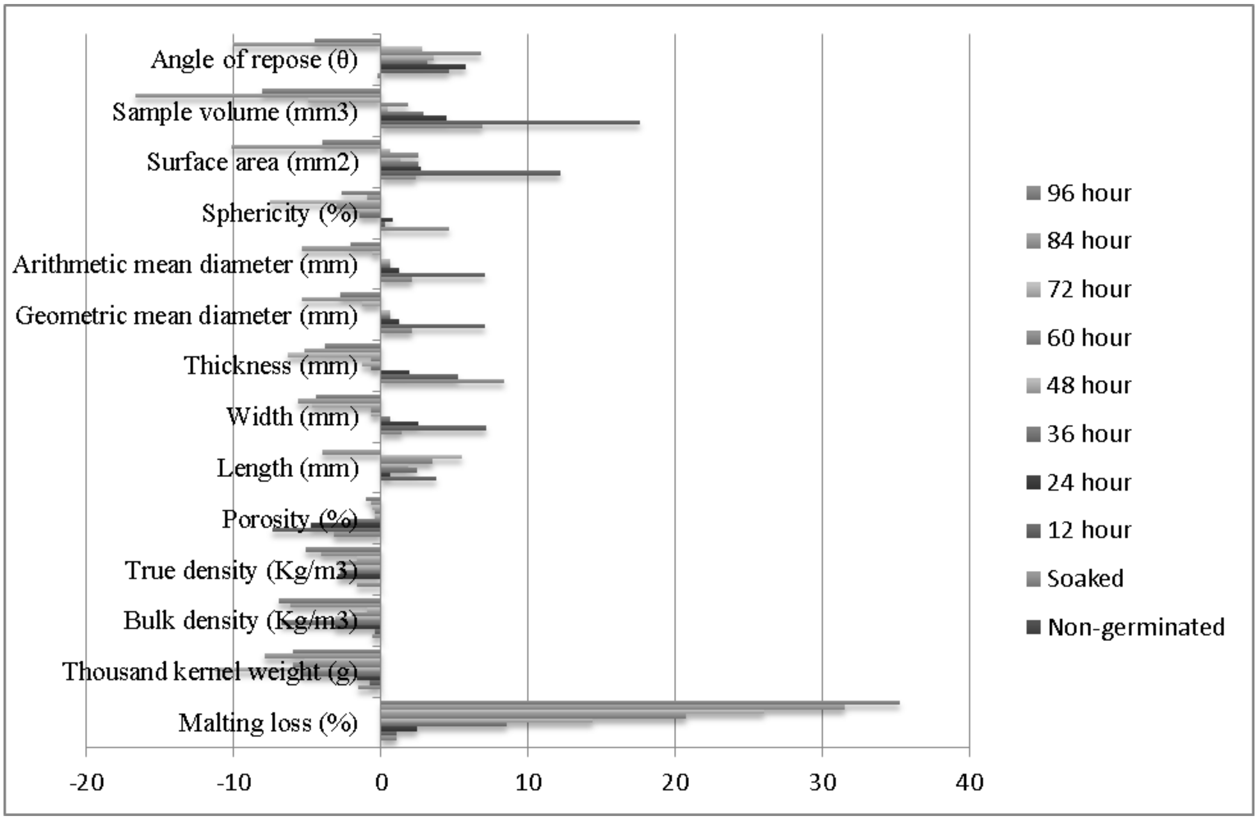

Figure 1. Effect of germination time on the malting loss and engineering properties in comparison to non-germinated finger millet grains (values for non-germinated parameters are taken as zero

Table 1. Effect of germination on malting loss and density related properties

Germination Time	Malting Loss (%)	Thousand Kernel Weight (g)	Bulk Density (Kg/m^3)	True Density (Kg/m^3)	Porosity (%)
Non-germinated	0.00^{i}	$2.60±0.02^{a}$	$741.04±1.66^{a}$	$1250.00±1.1.5^{a}$	$36.61±0.26^{a}$
Soaked	$1.03±0.21^{h}$	$2.56±0.02^{b}$	$736.66±0.56^{b}$	$1230.33±1.76^{b}$	$35.47±0.18^{b}$
12 hour	$1.10±0.10^{h}$	$2.54±0.03^{b}$	$733.41±0.54^{c}$	$1229.00±0.58^{b}$	$33.03±0.11^{c}$
24 hour	$2.49±0.09^{g}$	$2.50±0.03^{c}$	$711.20±1.08^{d}$	$1194.33±2.60^{c}$	$31.54±0.37^{d}$
36 hour	$8.52±0.45^{f}$	$2.37±0.02^{d}$	$666.10±0.66^{e}$	$1162.03±2.30^{d}$	$30.86±0.59^{d}$
48 hour	$14.37±0.51^{e}$	$2.13±0.03^{e}$	$645.75±1.55^{f}$	$1142.73±1.76^{e}$	$30.74±0.28^{e}$
60 hour	$20.71±0.65^{d}$	$2.01±0.03^{f}$	$633.3±1.00^{g}$	$1109.33±2.33^{f}$	$30.70±0.19^{e}$

72 hour	26.03±0.40^{c}	1.91±0.02^{g}	627.65±0.94^{h}	1091.73±0.88^{g}	29.93±0.04^{f}
84 hour	31.53±0.15^{b}	1.77±0.01^{h}	591.23±1.95^{i}	1049.03±1.00^{h}	30.92±0.07^{e}
96 hour	35.27±0.40^{a}	1.67±0.02^{i}	552.72±1.66^{i}	997.67±2.60^{i}	31.49±0.4^{d}

*Values are means ± SD of 5 replications. Different superscripts in a column indicate that they are significantly (P≤0.05) different to each other determined by Duncan's tests

Table 2. Effect of germination time on the dimensional properties of finger millet grains

Germination Time	Length (mm)	Width (mm)	Thickness (mm)	Geometric Mean Diameter (mm)	Arithmetic Mean Diameter (mm)
Non-germinated	1.52±0.03^{d}	1.40±0.06^{bc}	1.32±0.04^{cd}	1.41±0.04^{c}	1.41±0.04^{d}
Soaked	1.52±0.07^{d}	1.42±0.09^{bc}	1.44±0.13^{abc}	1.44±0.11^{bc}	1.44±0.11^{cd}
12 hour	1.58±0.09^{cd}	1.53±0.07^{a}	1.52±0.07^{ab}	1.55±0.07^{ab}	1.55±0.07^{abc}
24 hour	1.59±0.05^{cd}	1.57±0.04^{a}	1.55±0.04^{a}	1.57±0.04^{a}	1.57±0.04^{ab}
36 hour	1.63±0.03^{c}	1.58±0.05^{a}	1.54±0.05^{ab}	1.58±0.04^{a}	1.58±0.04^{a}
48 hour	1.66±0.07^{bc}	1.57±0.05^{a}	1.52±0.05^{ab}	1.59±0.06^{a}	1.59±0.06^{a}
60 hour	1.72±0.03^{b}	1.56±0.10^{a}	1.51±0.12^{ab}	1.59±0.08^{a}	1.59±0.08^{a}
72 hour	1.82±0.01^{a}	1.49±0.01^{ab}	1.42±0.01^{bc}	1.57±0.01^{a}	1.58±0.01^{a}
84 hour	1.75±0.01^{ab}	1.41±0.01^{bc}	1.35±0.02^{cd}	1.49±0.01^{abc}	1.50±0.01^{abcd}
96 hour	1.75±0.01^{ab}	1.35±0.01^{c}	1.30±0.01^{d}	1.45±0.01^{bc}	1.47±0.01^{bcd}

*Values are means ± SD of 5 replications. Different superscripts in a column indicate that they are significantly (P≤0.05) different to each other determined by Duncan's tests.

3.2. Dimensional properties

Grain dimensions like length, width, thickness, geometric mean diameter, arithmetic mean diameter are important in designing the sieves for separation of grains from undesirable materials. For the utilization of malted grains to develop value added products, it is important to remove vegetative growth and separate the sound grains from waste material. Maximum value for length (1.82) was obtained after 72 hours of germination while the value for width and thickness was highest at 36 hours and 24 hours of germination, respectively. The increase in dimensional properties like length, width and thickness of finger millet grains might have been due to the swelling of starch granules during soaking as water migrates to grains during soaking and leads to irreversible swelling (Mir and Bosco, 2013). One of the more reasons behind increase in length might be the adherence of dried epicotyl and hypocotyl to grain after drying as their complete removal is not possible. A prolonged germination resulted in decrease in dimensional properties which might have been due to the formation of pits and holes on the surface of germinated starch granules and formation of small size particles due to the breakdown of larger particles (Li *et al.*, 2017). A similar trend was observed in the geometric mean diameter and arithmetic mean diameter (Table 2).The diameter is dependent on length, width and thickness of grains and same has been observed in the correlation studies (Table 4). Width and thickness had a positive significant (P≤0.05) effect on geometric mean diameter and arithmetic mean diameter (fig. 1) and an increase in width and thickness increased the diameter. The studies on the effect of germination time on the dimensional properties of grains are scarce. However; increase in moisture has been reported to increase the dimensional properties of grains (Bai *et al.*, 2012; Gely and Pagano, 2017).

3.3. Surface and frictional properties

Surface properties play an important role in drying whether sphericity and frictional properties like angle of repose affects the rate of sliding of grains on a surface. Frictional properties are important in designing hoppers and storage structures like silos. The frictional properties of grains determine the rate of flow of grains, feed rate and also help to determine the rate of emptying of storage structures (Balasubramanian and Viswanathan, 2010). Surface and frictional properties of non-germinated finger millet and malted grains has been presented in Table 3.

Table 3. Effect of germination on surface and frictional properties of finger millet grains

Germination Time	**Sphericity (%)**	**Surface area (mm^2)**	**Sample volume (mm^3)**	**Angle of Repose (θ)**
Non-germinated	93.1 ± 0.97^{cd}	6.49 ± 0.32^{d}	1.48 ± 0.12^{c}	24.99 ± 1.07^{g}
Soaked	97.6 ± 0.76^{ab}	6.65 ± 0.99^{cd}	1.59 ± 0.36^{bc}	24.93 ± 0.52^{g}
12 hour	97.9 ± 1.05^{a}	7.57 ± 0.76^{abc}	1.93 ± 0.28^{ab}	26.14 ± 0.21^{f}
24 hour	98.7 ± 0.58^{a}	7.78 ± 0.44^{ab}	2.02 ± 0.17^{a}	27.73 ± 0.53^{e}
36 hour	97.3 ± 1.31^{ab}	7.98 ± 0.37^{ab}	2.08 ± 0.17^{a}	28.64 ± 0.25^{d}
48 hour	95.4 ± 1.12^{bc}	8.09 ± 0.60^{ab}	2.09 ± 0.22^{a}	29.71 ± 0.48^{c}
60 hour	92.6 ± 3.5^{d}	8.30 ± 0.71^{ab}	2.13 ± 0.32^{a}	31.89 ± 0.38^{b}
72 hour	86.1 ± 0.28^{e}	8.35 ± 0.01^{a}	2.03 ± 0.00^{a}	32.81 ± 0.48^{a}
84 hour	85.3 ± 0.47^{ef}	7.58 ± 0.04^{abc}	1.74 ± 0.02^{abc}	29.81 ± 0.33^{c}
96 hour	83.1 ± 0.22^{f}	7.29 ± 0.06^{bcd}	1.61 ± 0.02^{bc}	28.52 ± 0.29^{de}

*Values are means ± SD of 5 replications. Different superscripts in a column indicate that they are significantly ($P < 0.05$) different to each other determined by Duncan's tests

Sphericity, surface area and surface volume of the non-germinated finger millet grains was 93.1, 6.49 mm^2 and 1.48 mm^3, respectively. Bai et al. (2012) reported sphericity ranging from 0.94 to 0.99% for non-germinated finger millet grains. Ramashia et al. (2017) reported sphericity in the range of 73.75 to 92.43% for the black, creamy and brown cultivars of finger millet. With increase in germination time from 0 to 24 hours, sphericity was increased from initial 93.1% to 98.7%. The increase in sphericity up to 24 hours might be due to the swelling of starch granules on soaking (Mir and Bosco, 2013). Germination beyond 24 hours resulted in linear decrease in sphericity i.e. from 98.7% to 83.1%. The reason for decrease in sphericity after 24 hours of germination might be due to more increase in length as compared to width and thickness. An increase in surface area (6.49 to 8.30 mm^2) and sample volume (1.48 to 2.13 mm^3) was observed which might have been due to the increase in dimensional parameters like length, width and thickness (Table 2) and same has been observed in correlation studies (Table 4).

Table 4. Correlation of the effect of germination time on various engineering parameters

Parameters	Malting Loss (%)	Thousand kernel Weight (g)	Bulk Density (Kg/ m^3)	True Density (Kg/ m^3)	Porosity (%)	Length (mm)	Width (mm)	Thickness (mm)	Geometric Mean Diameter (mm)	Arithmetic Mean Diameter (mm)	Sphericity (%)	Surface Area (mm^2)	Sample Volume (mm^3)	Angle of Repose (θ)
Malting loss (%)	1	-.997**	-.976**	-.984**	-.647*	.922**	-.349	-.472	.043	.131	-.907**	.398	.047	.714*
Thousand kernel weight (g)		1	.980**	.983**	.676*	-.926**	.300	.426	-.092	-.179	.882**	-.438	-.096	-.738*
Bulk density (Kg/m^3)			1	.992**	.707*	-.887**	.247	.373	-.122	-.208	.827**	-.448	-.127	-.704*
True density (Kg/m^3)				1	.692*	-.895**	.294	.402	-.086	-.176	.852**	-.421	-.090	-.689*
Porosity (%)					1	-.815**	-.457	-.328	-.764*	-.820**	.337	-.923**	-.760*	-.879**
Length (mm)						1	-.060	-.220	.345	.427	-.793**	.669*	.347	.900**
Width (mm)							1	.951**	.910**	.868**	.636*	.701*	.912**	.314
Thickness (mm)								1	.819**	.769**	.767**	.557	.818**	.128
Geometric mean diameter (mm)									1	.995**	.286	.927**	.998**	.639*
Arithmetic Mean Diameter (mm)										1	.200	.955**	.991**	.690*
Sphericity (%)											1	-.089	.285	-.500
Surface area(mm^2)												1	.929**	.870**
Sample volume (mm^3)													1	.653*
Angle of repose (θ)														1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed)

An increase in surface area and sample volume has been also reported in maize, wheat and paddy on increase of moisture content (Adebowale *et al.,* 2012; Bai *et al.,* 2012; Gelly and Pagano, 2017). Soaking had a non-significant effect on angle of repose. However, a significant ($P \leq 0.05$) increase in angle of repose was found with increase in germination time. The reason for increase in angle of repose might be the adherence of dried epicotyl and hypocotyl to grain after drying which increased the overall friction and hence resulted in a high heap.

3.4. Cluster analysis

A dendrogram for different treatments (i.e. soaking time and germination time) on the engineering properties of finger millet grains is shown in Figure 2. Cluster analysis grouped the data in 2 major groups. The first group consists of soaked, 12 hour germinated grains, non-germinated grains and 24 hour germinated grains.

The second group consists of grains germinated for 36-96 hours. Group 2 was further subdivided into 2 subgroups and showed that the grains germinated for 60, 72, 36 and 48 hours were in same group and had the most similar engineering properties. While, the engineering properties of grains germinated for 84 hours and 96 hours were different from others.

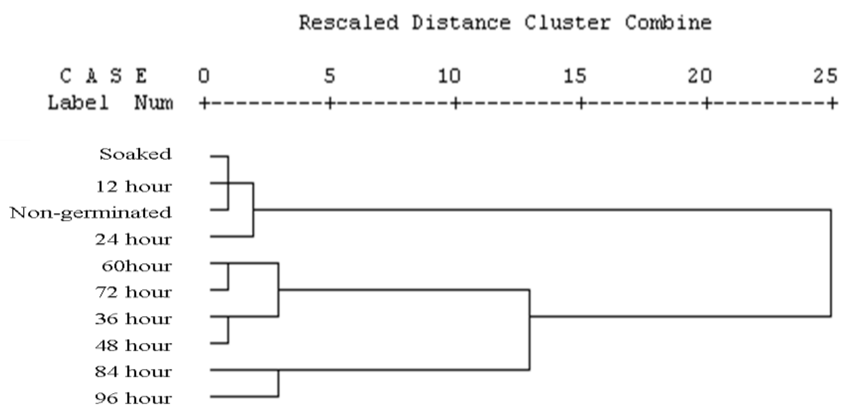

Figure 2. Dendrogram of the engineering properties of the finger millet grains as affected by the germination time

4.Conclusions

An increase in germination time of finger millet from 0 to 96 hours resulted in increased malting loss. Malting loss was directly proportional to thousand kernel weight, bulk density and true density and hence an increase in malting loss resulted in decreased values for these parameters. Initial germination time of 24 hours increased the dimensional and surface properties followed by a decrease on prolonged germination. Dendrogram grouped finger millet samples germinated for 0-24 hours in a single group and hence it can be concluded that existing handling equipments and storage structures can be used for finger millet germinated up to 24 hours with minimum changes. Correlation study suggests that malting loss had a significant effect on gravimetric and dimensional properties, which in turn affect the surface properties like surface area and sphericity. The change in sphericity had a significant effect on frictional properties like angle of repose. Therefore, in the light of results it is suggested that for extended germination time beyond 24 hours the material handling equipments and storage structures should be designed accordingly.

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