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Mechanical and thermal properties of ginger (*Zingiber officinale* Rosc.)

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Abstract

Mechanical properties of fresh and stored (under ambient conditions for 2 months) ginger rhizomes (*Zingiber officinale*) (cv. Himachal) necessary for the design of processing machineries, were determined. Thermal properties were determined for fresh and dry ginger. Mechanical properties like peel penetration force for primary, secondary and tertiary finger rhizomes increased from 0.45 N, 0.52 N and 0.51 N to 0.60 N, 0.70 N and 0.65 N, respectively; the peel compressive force at rupture increased from 20.12 N, 19.86 N and 17.56 N to 22.58 N, 21.21 N and 19.67 N, respectively, and the cutting force required to penetrate through peel increased from 31.56 N, 27.68 N and 26.57 N to 32.71 N, 28.93 N and 28.16 N, respectively, in fresh and stored ginger rhizomes. Thermal properties like specific heat, thermal conductivity and thermal diffusivity for fresh ginger were 3566.87 J kg^{-1} K^{-1}, 0.2916 W m^{-1} K^{-1} and 0.8609 x 10^{-7} m^2 s^{-1} and the corresponding values for dry ginger at 10% moisture content were 1918.81 J kg^{-1} K^{-1}, 0.0760 W m^{-1} K^{-1} and 1.7339 x 10^{-7} m^2 s^{-1}, respectively.

Keywords: ginger, mechanical property, thermal property, *Zingiber officinale.*

Introduction

Ginger, the rhizome of *Zingiber officinale* Rosc. is harvested at different stages of maturity for processing into value-added products. The fully matured crop is ready for harvest in about 8 months after planting when the leaves turn yellow, and start drying up gradually. The maturity of ginger rhizome is also ascertained by pressing the rhizomes with the nail of thumb. The force exerted by the thumb finger is felt by the person who senses the maturity of the rhizome. This varies from person to person and the need for quantification of the applied force for various post harvest operation arises. Harvesting of rhizomes is done manually with a spade or by using a digging fork and the clumps are lifted carefully, and then separated from the dried-up leaves, roots and adhering soil.

Ginger, during processing is subjected to various handling operations like harvesting, washing, peeling, etc. which causes damage in the form of splits, punctures and bruises.

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Further damage is also caused when it is raked, picked, loaded and transported to distant places by trucks which also cause various changes in physico-mechanical properties of ginger. Data on mechanical properties are thus important in the adoption and design of various handling, packaging, processing, storage and transportation systems. Thermal properties like specific heat, thermal conductivity and thermal diffusivity are essential for the design of driers and pulverizing equipments. Knowledge of thermal properties of food substances is also essential in the design of heat transfer, dehydrating and sterilizing equipments (Kaleemullaah & Kailappan 2004). However, adequate information on mechanical and thermal properties of ginger is not available and hence this study was undertaken to determine the mechanical and thermal properties of ginger.

Materials and methods

Studies on determining the mechanical and thermal properties of fresh and dry ginger were conducted at the College of Agricultural Engineering, Tamil Nadu Agricultural University, Coimbatore, during January 2009. Freshly harvested ginger (cv. Himachal) obtained from Nemmara (Palakkad District, Kerala) grown in raised beds of size 4 m x 1 m, harvested about 8 months after planting during January 2009 was used to determine the mechanical and thermal properties of fresh ginger. Dry ginger was obtained by sun drying the partially peeled ginger. Since ginger is used as vegetable, and is subjected to mechanical handling after harvest, it was stored for 2 months under ambient conditions (average temperature 34°C and RH 50%). This period was selected as the appearance of ginger remained fresh till the end of this period after which shrinkage occurred on the surface. Since mechanical operations like peeling, cutting, slicing and loading for transportation are done mostly for green ginger and not for fully dry ginger, the mechanical properties were studied for fresh and stored ginger. The thermal properties were studied for fresh and dry rhizomes. The moisture content of fresh, stored and dry ginger rhizomes was 82%, 75% and 9%, respectively.

Mechanical properties

Mechanical properties like firmness, cutting force and compressive force for freshly harvested and stored ginger rhizomes were determined in a texture analyzer (Stable Microsystems, TA XT2i) under test conditions summarized in Table 1. The rhizomes were split into primary, secondary and tertiary fingers and the mechanical properties were determined for each category. The test was replicated for three rhizomes in each category.

Penetration test

Penetration measures the firmness of rhizomes to estimate harvest maturity or post-harvest evaluation of firmness. For

Table 1. Test settings of texture analyzer to determine mechanical properties of ginger rhizomes

Test parameter	Penetration test	Cutting force test	Compression test
Type of probe	P2N needle	HDP/BSK blade	P-75 platen
Test module	Measure force in compression	Measure force in compression	Measure force in compression
Test option	Return to start	Return to start	Return to start
Pre test speed (mm s^{-1})	1.0	1.0	1.0
Test speed (mm s^{-1})	0.5	0.5	0.5
Post-test speed (mm s^{-1})	5.0	5.0	5.0
Distance (mm)	10	20	5
Trigger force (g)	10	10	10
Load cell (kg)	50	50	50

measurement of firmness, the probe carrier of texture analyzer was fitted with a 2 mm cylindrical probe (P2N). Ginger rhizomes were placed upon the flat plate of size 150 x 150 mm. The test was carried out at a probe speed of 0.5 mm s^{-1}. The maximum force required to penetrate the rhizome surface to a depth of 10 mm was taken from the force-deformation curve.

Cutting test

Cutting test was carried out to determine the force required to cut the ginger rhizome. The rhizomes were placed horizontally upon the flat plate of texture analyzer and a probe carrier fixed with a HDP/BSK blade set was brought in contact with the rhizome. Cutter speed of 0.5 mm s^{-1} was used with 50 kg load cell. The load against depth of cut of 10 mm was recorded continuously. Two peaks exhibited in the test are the force for cutting the peel and meat, respectively.

Compression test

The rhizome compression test simulates the condition of static loading that ginger rhizomes can withstand during mechanical handling and storage. Force deformation characteristics of rhizomes beyond the elastic limit may be important to simulate the destruction that occurs during bruising. Ginger rhizome was placed horizontally upon the flat plate of texture analyzer and a probe carrier fixed with a 65 mm diameter flat plate was brought in contact with ginger. A 50 kg load cell was used and compression force was applied at a speed of 0.5 mm s^{-1} to compress the rhizome for 5 mm from the contact point. The firmness was expressed as the force required for compressing the rhizome to a distance of 5 mm.

Thermal properties

Thermal properties like specific heat, thermal conductivity and thermal diffusivity were determined for fresh and dry ginger rhizomes.

Specific heat

Specific heat is the property needed in the estimation of amount of energy required to change the temperature of the product and was determined by the method of mixtures by equating the heat lost by the hot sample in water to the heat gained by water from the hot sample (Kaleemullah & Kailappan 2004).

Thermal conductivity

Thermal conductivity is the property of a material describing its ability to conduct heat. Thermal conductivity was determined using the transient heat flow method in a line heat source apparatus similar to the one used by Sreenarayanan *et al*. (1988).

Thermal diffusivity

Thermal diffusivity is obtained as the ratio of thermal conductivity of the material to its volumetric heat capacity. The thermal diffusivity of fresh and dry ginger was calculated using the following equation (Mohsenin 1986):

$$D_{td} = \frac{K}{\rho \times C_p}$$

Where, D_{td} is the thermal diffusivity, $m^2 s^{-1}$; K is the thermal conductivity, $Wm^{-1} K^{-1}$; ρ is the bulk density of ginger, kg m^{-3}; C_p is the specific heat of ginger, kJ $kg^{-1} K^{-1}$.

Analysis

The mechanical and thermal properties obtained were analyzed by AGRES (Version 7.01, Pascal Intl. software solutions) statistical software.

Results and discussion

Mechanical properties

Penetration test

Peel penetration force of primary, secondary and tertiary finger rhizomes of ginger increased from 0.45 N, 0.52 N and 0.51 N to 0.60 N, 0.70 N and 0.65 N for fresh and stored ginger rhizomes, respectively (Table 2). Thus during storage, there was an increase in penetrative force and this varied as 33.33%, 34.62% and 27.45% for primary, secondary and tertiary fingers, respectively. Analysis of

Table 2. Penetration force of fresh and ambient stored ginger (2 months)

Category of rhizome	Fresh ginger		Stored ginger		Increase in value (%)	
	Peel	Meat	Peel	Meat	Peel	Meat
Primary finger	0.45	11.73	0.60	11.92	33.33	1.62
Secondary finger	0.52	11.69	0.70	11.88	34.62	1.63
Tertiary finger	0.51	10.95	0.65	11.82	27.45	7.95
	Peel			Meat		
	SED	CD (0.05)	F	SED	CD (0.05)	F
Rhizome category	0.013	0.029	20.89*	0.271	0.589	1.61 (NS)
Storage	0.011	0.024	207.03**	0.221	0.481	3.55 (NS)
Rhizome category x Storage	0.018	0.041	1.21 (NS)	0.383	0.833	1.05 (NS)

**=Significant at 1% level; *=Significant at 5% level; NS=Non-significant

variance indicated that both category of rhizomes and storage significantly influenced the penetrative force into the peel of ginger; however their interaction was non-significant.

The meat penetration force for primary, secondary and tertiary finger rhizomes increased from 11.73 N, 11.69 N and 10.95 N to 11.92 N, 11.88 N and 11.82 N for fresh and stored rhizomes, respectively. This corresponded to an increase of 1.62%, 1.63% and 7.95% during storage; however this increase was non-significant. Thus the category of rhizomes, storage and their interaction did not affect the penetrative force into the meat of ginger.

During storage the loss of moisture from the peel is continuously replenished by movement of moisture from the inner core. If this loss due to respiration and transpiration goes unchecked, the fruit/vegetable shrivels up, the firmness decreases and becomes unmarketable. The value of penetrative force indicates the firmness of the vegetable which in turn indicates the freshness of the produce. This property is important in designing the peeling devices as it indicates that peeling is easier when the rhizomes are fresh and when delayed, the removal of peel from ginger becomes very difficult.

Compression test

The rupture force is the peak force of compression test. The peel compressive force at rupture for primary, secondary and tertiary finger rhizomes increased from 20.12 N, 19.86 N and 17.56 N to 22.58 N, 21.21 N and 19.67 N for fresh and stored ginger rhizomes, respectively (Table 3). Thus, during storage,

Table 3. Compressive force of fresh and ambient stored ginger (2 months)

Category of rhizome	Fresh ginger		Stored ginger		Increase in value (%)	
	Peel	Meat	Peel	Meat	Peel	Meat
Primary finger	20.12	202.21	22.58	244.58	12.23	20.95
Secondary finger	19.86	191.63	21.21	226.50	6.80	18.19
Tertiary finger	17.56	169.97	19.67	182.63	12.02	7.45
	Peel			Meat		
	SED	CD (0.05)	F	SED	CD (0.05)	F
Rhizome category	0.466	1.016	18.15*	4.723	10.293	52.23*
Storage	0.381	0.829	26.88*	3.857	8.404	11.78*
Rhizome category x Storage	0.659	1.436	0.74 (NS)	6.681	14.556	5.34 (NS)

*=Significant at 5% level; NS=Non-significant

the compressive force of ginger peel increased significantly and this increase corresponded to 12.23%, 6.80% and 12.02% for primary, secondary and tertiary finger rhizomes. The variation in compressive force between the category of rhizomes was also significant; however their interaction was found to be non-significant.

The ginger meat compressive force for primary, secondary and tertiary finger rhizomes increased from 202.21 N, 191.63 N and 169.97 N to 244.58 N, 226.50 N and 182.63 N for the fresh and stored rhizomes, respectively. The increase in ginger meat compressive force during storage for primary, secondary and tertiary finger rhizomes was 20.95%, 18.19% and 7.45%, respectively. Thus the category of rhizome and storage significantly influenced the meat compressive force of ginger; however their interaction was found to be non-significant.

Compression test simulates the condition of static loading, that any fruit or vegetable can withstand in mechanical handling and storage without bruising. The data is useful in the design of mechanical washers, peelers and also during the bulk storage of ginger rhizomes.

Cutting force test

The cutting force test was performed to determine the force necessary to cut the peel and meat of ginger. The cutting force required for penetrating through the peel of fresh primary, secondary and tertiary fingers was 31.56 N, 27.68 N and 26.57 N and increased to 32.71 N, 28.93 N and 28.16 N for stored rhizomes, respectively (Table 4). The cutting force of ginger peel increased during storage corresponding to 3.64%, 4.04% and 5.98% for primary, secondary and tertiary finger rhizomes. However, this increase in cutting force during storage was non-significant. The value of cutting force thus obtained indicates the maximum force needed to cut through the peel without injuring the whole ginger. The data is useful in the design of mechanical peelers for ginger.

The cutting force required to penetrate the meat of fresh ginger primary, secondary and tertiary fingers was 131.58 N, 124.85 N and 117.32 N and increased correspondingly to 156.95 N, 137.97 N and 126.27 N after 2 months of storage. Thus, there was a significant increase in the cutting force of meat and this increase corresponded to 19.28%, 10.51% and 7.09% for primary, secondary and tertiary finger rhizomes. Analysis of variance indicated that the category of rhizomes also influenced the cutting force of rhizomes significantly. This data finds an important application in the

Table 4. Cutting force of fresh and ambient stored ginger (2 months)

Category of rhizome	Fresh ginger		Stored ginger		Increase in value (%)	
	Peel	Meat	Peel	Meat	Peel	Meat
	Peel	Meat	Peel	Meat	Peel	Meat
Primary finger	31.56	131.58	32.71	156.95	3.64	19.28
Secondary finger	27.68	124.85	28.93	137. 97	4.04	10.51
Tertiary finger	26.57	117.32	28.16	126.27	5.98	7.09

	Peel			Meat		
	SED	CD (0.05)	F	SED	CD (0.05)	F
Rhizome category	0.678	1.478	27.75*	3.072	6.695	26.92*
Storage	0.554	1.207	5.77 (NS)	2.509	5.466	39.72*
Rhizome category x Storage	0.959	2.090	0.06 (NS)	4.346	9.468	3.85 (NS)

*=Significant at 5% level; NS=Non-significant

development of mechanical slicers for producing ginger flakes.

Thermal properties

Specific heat

The specific heat of fresh ginger was 3566.87 J kg^{-1} K^{-1} and decreased to 1918.81 J kg^{-1} K^{-1} for dry ginger (Table 5). There was a significant decrease in specific heat of fresh ginger rhizomes after drying and the decrease corresponded to 73.94% of the initial value. The data on specific heat is useful in the design of driers and for thermal processing of ginger.

Thermal conductivity

The thermal conductivity of fresh ginger was 0.2916 W m^{-1} K^{-1} and decreased to 0.0760 W m^{-1} K^{-1} for dry ginger (Table 5). There was significant decrease in thermal conductivity of ginger after drying which corresponded to 46.21%. The data on thermal conductivity is useful in the design of driers and for thermal processing of ginger.

Thermal diffusivity

The thermal diffusivity of fresh ginger was 0.8609 x 10^{-7} m^2 s^{-1} and increased to 1.7339 x 10^{-7} m^2 s^{-1} for dry ginger (Table 5).

Table 5. Thermal properties of fresh and dry ginger

Category	Fresh ginger	Dry ginger	Increase/decrease in value (%)
Thermal conductivity (W m^{-1} K^{-1})	0.2916	0.0760	(-) 73.94
Specific heat (J kg^{-1} K^{-1})	3566.87	1918.81	(-) 46.21
Thermal diffusivity (m^2 s^{-1})	0.8609 x 10^{-7}	1.7339 x 10^{-7}	(+) >100
	SED	CD (0.05)	F
Thermal conductivity	0.007	0.193	959.80**
Specific heat	93.54	259.70	310.45**
Thermal diffusivity	0.000000016	0.00000002	381.26**

**=Significant at 1% level

The data obtained on mechanical properties of fresh and stored ginger rhizomes are useful in the design of mechanical washers, peelers, slicers, etc. Data on thermal properties of ginger finds its application in the design of driers and during thermal processing of ginger.

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