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AGRICULTURAL MATERIALS HANDLING MANUAL

PART 7 ENGINEERING PROPERTIES

SECTION 7.1

PROPERTIES OF AGRICULTURAL MATERIALS

Agriculture Canada

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PROPERTIES OF AGRICULTURAL MATERIALS

The Agricultural Materials Handling Manual is produced in several parts as a guide to designers of materials handling systems for farms and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

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SECTION 7.1 PROPERTIES OF MATERIALS

7.1.1 DEFINITIONS

7.1.1.1 List of Symbols Used in Definitions

Parameter	*Symbol*
Bulk density	β
Shearing strainy	γ
Angle of repose	θ
Angle of internal friction	φ
Coefficient of friction	μ_c
Coefficient of viscosity	η
Compression stress	σ
Shear stress	τ
Strain	ε
Real permittivity	ε_o
Elastic modulus	E
K-ratio	K
Proportional limit	$\sigma_{p.l.}$
Modulus of rigidity	G
Modulus of resiliency	μ_r
Strain energy	U
Specific heat	S
Temperature	T
Thermal diffusitivity	α
Thermal conductivity	k
Dielectric constant	E_o
Total shearing deformation	e_s
Temperature	Θ
Time	t
Retardation force	F
Terminal velocity	V

7.1.1.2 **Physical Properties**

1. Bulk Density - *β:* The mass of a substance divided by the volume of that substance. This is not to be confused with specific gravity. Wheat, with a specific gravity of 1.30 might be expected to have a bulk density of 1.30 x 1000 (the mass of $1m^3$ foot of water) or 1300 kg/m^3. However, due to the presence of air spaces, the actual bulk density of wheat may be 763 kg/m^3

2. Fineness Modulus: Used to indicate the uniformity of grind or distribution of fine, medium, and coarse particles in the product. The fineness modulus is defined as the sum of the mass fractions retained above each sieve or screen divided by 100. The following example illustrates how it may be found and expressed:

Screen mesh		*% of material retained*	*Multiplied by*	
9.5 mm	$^3/_8$ in.	1.0	7	7.0
6.3	no. 4	2.5	6	15.0
3.2	8	7.0	5	35.0
1.8	14	24.0	4	96.0
0.91	28	35.5	3	106.5
0.53	48	22.5	2	45.0
0.25	100	7.5	1	7.5
	Pan	0.0	0	0.0
		Totals 100.0		312.0
		Fineness modulus 312 / 100 = 3.12		

3. Freezing Point: Temperature at which the water in the material freezes.
4. Shape: An approximate geometric description of the material.
5. Size: The size of grains will be divided into five classes; Class A, very fine (will pass through 0.25 mm mesh); **B,** fine (will pass through 3.2 mm mesh, but not through 0.25 mm mesh); C, (will pass through 6.3 mm mesh, but not through 3.2 mm mesh); D, lumpy (greater than 6.4 mm across); and H, irregular. Other materials, if not describable in these terms, will be described approximately.
6. Specific Gravity: The ratio of the mass of a substance over the mass of an equal volume of water at 4°C., or other specified temperature. Since the specific gravity of water at 4°C is taken as 1, a substance whose specific gravity is less than 1 will float in water, and one whose specific gravity is greater than 1 will sink.
7. Surface Texture: A general description of the surface of the material.
8. Uniformity Index: The modulus of uniformity shall be expressed by three numbers representing the coarse, the medium, and the fine particles, the sum of which shall always equal 10. For example, the ratio 1:6:3 represents the proportionate amounts of coarse, medium and fine particles, respectively, in a particular sample of ground feed, and thus expresses the uniformity of that sample of ground feed. The material remaining after a size analysis on the 9.5 mm and 3.2 mm mesh screens shall be designated as "coarse", and that on the 1.8 mm and 0.91 mm mesh screens as "medium" and that on the 0.53 and 0.25 mm mesh screens and in the pan as "fine".
9. Unit Measure of Handling: One unit is considered to be the amount of material which is handled as one unit article. In cases where the amount of material in a unit is not self-explanatory (e.g. crate, box, etc.), dimensions of the container will be specified.
10. Unit Mass: The mass of one unit measure.

7.1.1.3 **Mechanical Properties**

1. Angle of Repose - *θ :* The angle of repose is the natural slope which a granular mass will assume, when the slope is formed without the granular mass dropping through a vertical distance.
2. Angle of Internal Friction -φ: The angle of internal friction is the angle whose tangent is the coefficient of the internal friction between particles and which reaches the limit in a right angle. This angle is shown when part of the pile of non-free-flowing material is removed and the cavity ceases to fill. For non-free-flowing materials, the angle of internal friction and the angle of repose are not synonymous because of the presence of interlocking and cohesive forces.
3. Abrasian Resistance: A measure of the force or torsion required before abrasive wear begins to damage the material, e.g. the tangential force that will cause the skin of a potato to scrape off.
4. Coefficient of Friction - *μ :* The coefficient of friction between two substances is defined as the ratio of the force required to slide one substance over the other, divided by the normal force pressing the two surfaces together.
5. Compression Stress - *σ* (MPa or N/mm^2): A measure of

the force per unit area which causes a material to yield or rupture. The ultimate stress of a substance is defined as the maximum force over a unit area:

$$\sigma = P / A \quad (1)$$

where σ = unit stress
P = applied force
A = area of loading

This equation only applies for uniform loading. For a non-uniform loading in either tension or compression:

$$\sigma = dP / dA \quad (2)$$

where the incremental force dP is divided by the differential area dA.

6. Dielectric Constant - E_o: Also called permittivity, the units are farad/metre (F/m). It is the ratio of the electric flux density produced in a medium to that which would be produced in a vacuum by the same electric flux.

7. Impact Resistance: A measure of the energy required to cause mechanical damage to a material through impact loading (e.g. a plunger falling through a distance onto an apple).

8. Heat of Respiration (Evolution): The quantity of heat evolved as a result of the respiration processes of agriculture products, usually measured in units of MJ/(t·d) or kJ/(kg·d).

9. K-ratio: This is defined as the $\frac{\text{lateral pressure}}{\text{vertical pressure}}$

10. Latent Heat: The heat which is required to change the state of a substance from solid to liquid or liquid to gas, without a change of temperature. In agricultural materials it is the heat which the product gives off or takes up when it thaws or freezes. It is expressed as heat/unit mass, in J/kg.

11. Modulus of Elasticity - E (MPa): The ratio of the stress over the strain:

$$E = 4 / \varepsilon \quad (3)$$

$$E = \frac{P/A}{e/L} = \frac{PL}{Ae}$$

where P = force applied in Newtons
L = length of specimen, mm
e = increase in length of specimen, mm
A = area over which P acts, mm^2

12. Modulus of Resiliency - μ_r : The modulus of resiliency represents the total area under the stress-strain curve up to the proportional limit (p.l.). It represents the energy that can be absorbed per unit without permanent distortion. For materials which exhibit a linear relationship between stress and strain up to proportional limit:

$$\mu_r = \tfrac{1}{2} (4_{p.l.}) (\varepsilon)$$

but $\varepsilon = \sigma / E$

$$\therefore \mu^r = \tfrac{1}{2} \sigma_{p.l.} (\sigma_{p.l.}/E) = (1/2E) (4_{p.l.})^2 \quad (4)$$

where μ_r = modulus of resiliency Pa
$4_{p.l.}$ = proportional limit stress Pa
E = modulus of elasticity MP,

13. Modulus of Rigidity - G: A body under shear stress undergoes a change in shape. The relation between shearing stress and shearing strain, defined as the angular change between two perpendicular faces of a differential element, is given as follows:

$$\tau = G \gamma \quad (5)$$

where G = modulus of rigidity or modulus elastic shear
γ = shearing strain
τ = shearing stress applied

Shearing strain is derived from the total shearing deformation e in the length L, as follows:

$$\tan \gamma = e_s / L \quad (6)$$

where tan γ is in radians

14. Specific Heat - S: Specific heat of a substance is the ratio of its thermal capacity to that of water at 15°C. If a quantity of heat Q J is necessary to raise the temperature of M kg of a substance from t_1 to t_2 °C, the specific heat, or more properly, thermal capacity of the substance, is:

$$S = Q /[M (t_1 - t_2)] \quad (7)$$

15. Strain Energy - U: The work done, stored as elastic strain energy in a body, is the product of the average force ½ P and the deformation e = PL / AE

$$U = P^2L / 2AE \quad (8)$$

16. Terminal Velocity: Any body moving through a fluid experiences a retarding force due to the viscosity of the fluid. In general, it is not possible to calculate this force, except for a sphere moving without slip in an infinite field of fluid. Stokes has shown that a retarding force (F) is given by the expression:

$$F = 3 \pi D \eta V \quad (9)$$

where η is the viscosity of the fluid, D the diameter of the sphere and V its terminal velocity through the field in a consistent set of units.

Stokes' equation defined the terminal or steady-state velocity of particles moving under an accelerating force with streamlined flow.

$$V= 2a^2 (\gamma_p - \gamma)g / 9\eta \quad (10)$$

where V = velocity, m/s
a = radius, m
γ_p = density of particle, kg/m^3
γ = density of fluid medium, kg/m^3
g = gravitational or accelerating force, m/s^2
η = viscosity, Pa

17. Thermal Conductivity - k: The coefficient of thermal conductivity or the specific thermal conductivity k of a substance is the quantity of heat which flows in 1 hour through a unit area of a slab of the substance of unit thickness when the temperature of the faces of the slab differ by 1 degree. If Q is the quantity of heat conducted in t hours across area A of a slab thickness d metres whose faces are at temperature Θ and Θ_2, then:

$$Q / t = [k A (\Theta_1 - \Theta_2)] / d \quad (11)$$

expressed in MJ/(h·m·°C).

18. Thermal Diffusivity- α :The rate at which the temperature of a body changes with change in time for unsteady state heat flow. It is equal to the quantity k^3/C, where k is the thermal conductivity, ^{3} the density, and C the specific heat per unit mass. Expressed in m^2/h.

7.1.1.4 **Storage Characteristics**

1. Moisture Content: The moisture content of a substance can be determined in two ways. Each specifies the amount of moisture present in the material but use different sample weights as basis of comparison.

$$\text{Wet basis M.C.} = \frac{\text{mass of water in sample}}{\text{mass of original sample}} \times 100\%$$

$$\text{Dry basis M.C.} = \frac{\text{mass of water in sample}}{\text{mass of dry material}} \times 100\%$$

(Note - use of mass of dried sample may be misleading, since the sample may not be completely dried. See Hall, *Drying Farm Crops,* pages 11 and 12).

2. Equilibrium Moisture Content: Crops containing moisture have internal vapor pressures that depend on the moisture content of the material and its temperature. If this internal vapor pressure is greater than the partial pressure of the water vapor in the surrounding air, the material will lose moisture to the air until the vapor pressures are equal. The material will take up moisture from the air if these relations are reversed. The moisture content existing when the vapor pressures are equal at identical temperatures of the air and the material, is called the equilibrium moisture content. The amount of moisture present at equilibrium for a given temperature can be related to the relative humidity.

3. Maximum and Minimum Storage Temperature: Temperatures at which physiological disorders are minimized and the product can be maintained in a saleable condition for an economically useful period.

4. Recommended Storage Humidity: The values given are in percent and are the recommended relative humidity for maximum storage life.

$$\text{relative humidity} = \frac{\text{partial pressure of water vapor}}{\text{saturation vapor pressure at the same temperature}} \times 100\%$$

5. Recommended Storage Temperature: Values are given in degrees Celsius and indicate the recommended temperature for maximum storage life.

6. Safe Storage Moisture Content: The moisture content at which a material may be safely stored without spoilage under optimum conditions, i.e. recommended temperature and humidity.

7. Storage Life: The maximum time a material can be stored without spoilage under optimum conditions, i.e. recommended temperature and humidity.

7.1.1.5 **Handling Characteristics**

1. Abrasiveness: Abrasiveness will be broken up into three classes; class 1 - non-abrasive; class 2 - mildly abrasive; and class 3 - very abrasive.

2. Aerationability: If a material aerates and acquires fluid characteristics, it will be denoted by Y for yes, or N for no.

3. Contaminability: If a material is easily contaminable with foreign material, affecting its saleability or use, it will be denoted by Y for yes, or N for no.

4. Explosive Dusting: If a material contains explosive dust, it will be denoted by Y for yes, or N for no.

5. Flowability: There are three classes; class 1, very free-flowing (angle of repose up to 30°); class 2, free-flowing (angle of repose between 30° and 45°); and class 3, sluggish (angle of repose greater than 45°).

6. Packing under Pressure: If a material packs under pressure, it will be denoted by Y for yes, and N for no.

7.1.2 **MATERIALS CLASSIFICATION**

7.1.2.1 **Fruits**

1. Apples
   (a) Jonathon
   (b) McIntosh
   (c) Golden delicious
   (d) Red delicious
   (e) Northern spy
   (f) Rome beauty
   (g) Winesap
2. Apricots
3. Berries
   (a) Blackberries
   (b) Cranberries
   (c) Gooseberries
   (d) Raspberries - red
   (e) Raspberries - black
   (f) Strawberries
4. Cherries
   (a) Sweet
   (b) Sour
5. Grapes
   (a) Vinifera
   (b) American
6. Peaches
   (a) Early
   (b) Late
7. Pears
   (a) Bartlett
   (b) Small
   (c) Winter, fall
8. Plums

7.1.2.2 **Vegetables**

1. Asparagus
2. Beans
   (a) Green or snap
   (b) Lima
3. Beets
   (a) Red - topped
   (b) Red - bunched
4. Broccoli
5. Brussel sprouts
6. Cabbage
   (a) Early
   (b) Late
7. Carrots

(a) Topped
(b) Bunched
8. Cauliflower
9. Celery
10. Corn (cob)
(a) Popcorn
(b) Sweet corn
(c) Soft corn
(d) Flint corn
(e) Dent corn
11. Corn (shelled)
(a) Popcorn
(b) Sweet corn
(c) Soft corn
(d) Flint corn
(e) Dent corn
12. Cucumbers
13. Eggplant
14. Garlic
15. Lettuce
16. Melons
(a) Watermelon
(b) Cantaloupe
(c) Honeydew
17. Onions
18. Onions, green-bunched
19. Parsnips
20. Peas
21. Peppers
22. Potatoes
(a) Katadhin
(b) Chippewa
(c) Green mountain
(d) Cobbler
(e) Netted gem
(f) Sweet potato
23. Pumpkins
24. Rutabaga
25. Radishes
(a) Spring
(b) Winter
26. Spinach
27. Squashes
(a) Summer
(b) Winter
28. Sugar beets
29. Tomatoes
(a) Ripe
(b) Mature green
30. Turnips

7.1.2.3 **Grains and Seeds**

1. Alfalfa
2. Barley
3. Beans
(a) Lima - dry
(b) Lima - unshelled
(c) Snap
4. Bluegrass
5. Broom corn
6. Bromegrass
7. Buckwheat
8. Castor beans
9. Clover
10. Corn
(a) Ear
(b) Shelled
11. Fescue
12. Flaxseed
13. Grain sorghum
14. Millet
15. Mustard
16. Oats
17. Orchard grass
18. Rapeseed
19. Rice
(a) Rough
(b) Smooth
20. Rye
21. Sorgo
22. Soybeans
23. Sunflower seeds
24. Timothy
25. Vetch
26. Walnuts
27. Wheat
28. Sudan grass
29. Peas

7.1.2.4 **Non-agricultural Materials**

1. Clay
2. Silt
3. Sand
(a) Fine - dry
(b) Fine - wet
(c) Coarse - dry
(d) Coarse - wet
4. Gravel 6.4 mm ($^1/_4$ in.)
5. Earth, avg.
6. Peat
7. Coal
(a) Anthracite
(b) Bituminous
8. Coke
9. Mud, soft-flowing

7.1.2.5 **Processed Feeds**

1. Alfalfa meal
2. Ground barley
3. Malt barley
4. Beans (cull)
5. Bean screenings
6. Dried beet pulp
7. Bone meal
8. Brewer's grains
9. Bran (wheat)
10. Betonite
11. Corn meal
12. Fish meal

13. Linseed oil meal (solvent process)
14. Malt (dry ground)
15. Meat and bone scrap
16. Beet molasses
17. Cane or blackstrap molasses
18. Corn sugar molasses
19. Oat meal
20. Ground oats
21. Rolled oats
22. Peas (cull)
23. Pea screenings
24. Poultry-byproducts meal
25. Rapeseed oil
26. Rice bran
27. Safflower seed oil meal
28. Safflower oil feed
29. Safflower hulls (ground)
30. Salt
31. Dried skimmed milk
32. Tomato pomace (dried)
33. Wheat germ
34. Wheat flour
35. Wheat middlings (short on Pacific coast)
36. Wheat red dog (middlings on Pacific coast)
37. Hay wafers

7.1.3 TABLES OF PHYSICAL PROPERTIES

TABLE 7.1.1 Unit Measures (Units of Handling and Unit Weights).

Product	Unit of Handling	Unit Weight (lb)	Unit Of Handling	Unit Mass (kg)	(Ref)
FRUITS					
Apples	bushel box	45	36.4 L	20.4	11
	crate	45	36.4 L	20.4	11
	11 quart open	14	12.5 L	6.3	11
	transparent bag	3 or 5		1.4 or 2.3	11
Apricots	carton		362 x 292 x 159 mm		11
Cherries - sweet	carton	50	413 x 305 x 133 mm	22.7	11
- sour	same as for sweet cherries				
Grapes	bushel	50	36.4 L	22.7	11
	11 quart open	14	12.5 L	6.3	11
Peaches - early	crate		410 x 292 x 121 mm		11
Pears - Bartlett	carton		438 x 279 x 222 mm		11
- fall, winter	11 quart		12.5 L		11
Plums	crate		510 x 292 x 121 mm		14
Raspberries	quart	1 ¼	1.1L	0.6	11
Strawberries	quart	1 ¼	1.1L	0.6	11
Blackberries	quart	1 ¼	1.1L	0.6	11
Gooseberries	quart	1 ¼	1.1L	0.6	11
VEGETABLES					
Potatoes	bag	5 bag		2.27	11
	bag	10 bag		4.54	11
	bag	20 bag		9.07	11
	bag	50 bag		22.7	11
	sack	100 sack [1]		45.4[1]	11[1]

TABLE 7.1.1 Unit Measures (Units of Handling and Unit Weights).

Product	Unit of Handling	Unit Weight (lb)	Unit Of Handling	Unit Mass (kg)	(Ref)
VEGETABLES					
Asparagus	Eastern crate	12	Eastern crate	5.4	12
	Western crate	15	Western crate	6.8	12
Beans	11 quart	11	11quart	5	12
Beans - Lima	bushel	32	bushel	14.5	68
Beets - red-topped	bag or carton	50	bag or carton	22.7	11
Brussel sprouts	bag or cup	10 oz	bag or cup	0.283	11
Cabbage - early	bag or carton	1	bag or carton	0.454	
Carrots - topped	bag	50	bag	11.3	11
		75		34	11
Cauliflower	bushel	27	bushel	12.2	12
Celery	crate (B.C.)	50	crate (B.C.)	22.7	12
	crate (Ont.)	65	crate (Ont.)	29.5	12
Cucumbers	bushel	50	bushel	22.7	12
	11 quart	16	11 quart	7.3	12
Eggplant	bushel	33	bushel	15	
Lettuce	large crate	70	large crate	31.7	68
	bushel	18	bushel	8.2	12
Watermelons	one (average size)	25	one (average size)	11.3	68
Cantaloupe	jumbo crate	70	jumbo crate	31.7	12
Honeydew melons	jumbo crate		jumbo crate		
	(7 3/4 x16x 21 7/8 in.)	44	(197 x 406 x 556 mm)	20	68
Onion	sack	10	sack	4.54	11
		25		11.3	11
		50		22.7	11
Parsnips	bag	2	bag	0.907	12
		25		11.3	12
		50		22.7	12
Peas	bushel (shelled)	50	bushel (shelled)	22.7	12
	11 quart (in pod)	10	12.5 L	4.5	11
Peanuts - shelled	bushel (Virginia type)	33	bushel (Virginia type)	15	68
- unshelled	bushel (Virginia type)	22	bushel (Virginia type)	10	68
Peppers	bushel	25	bushel	11.3	68
	11 quart	9	12.5 L	4.1	11
Rhubarb	crate	10	crate	4.5	11
		20		9.07	11
		40		18.1	11
		50		22.7	11
Rutabaga	bag	25	bag	11.3	11
		50		22.7	11
Spinach	bushel	18	bushel	8.2	12
Tomatoes - ripe	box or crate and multiple of	5	box or crate and multiple of	2.27	11
Turnips	bushel	50	bushel	22.7	12
Radishes - spring	dozen bunches	3	dozen bunches	1.4	12
Sugar beets					
SEEDS AND GRAINS					
Alfalfa	bushel	$60m^3$		742.4	11
Barley	bushel	$48m^3$		593.9	11
Beans - dry	bushel	$60m^3$		742.4	11
Blue grass	bushel	$18m^3$		222.7	11
Bromegrass	bushel	$14m^3$		173.2	11
Buckwheat	bushel	$48m^3$		593.9	11
Castor beans	bushel	$46m^3$		569.2	68
Clover	bushel	$60m^3$		742.4	11
Corn - shelled	bushel	$56m^3$		692.9	11
Fescue	bushel	$22m^3$		272.2	11
Flaxseed	bushel	$56m^3$		692.9	11
Grain sorghum	bushel	$56m^3$		692.9	68
Millet	bushel	48 - $50m^3$		593.9 - 618.5	11

TABLE 7.1.1 Unit Measures (Units of Handling and Unit Weights).

Product	Unit of Handling	Unit Weight (lb)	Unit Of Handling	Unit Mass (kg)	(Ref)
SEEDS AND GRAINS					
Oats	bushel	34	m^3	420.7	11
Orchard seed	bushel	14	m^3	173.2	11
Rapeseed	bushel	50	m^3	618.6	11
Rice - rough	bushel	45	m^3	556.8	68
Rye	bushel	56	m^3	692.9	11
Sorgo	bushel	50	m^3	618.6	68
Soybeans	bushel	60	m^3	742.4	11
Sunflower seeds	bushel	30	m^3	371.2	11
Tares	bushel	61.25	m^3	757.8	56
Timothy	bushel	48	m^3	593.9	11
Vetch	bushel	60	m^3	742.4	11
Walnuts	bushel	50	m^3	618.6	68
Wheat	bushel	60	m^3	742.4	11
Sudan grass	bushel	40	m^3	494.9	68
Peas	bushel	60	m^3	742.4	11
PROCESSED FEEDS					
Alfalfa meal	bushel	25	m^3	309.3	56
Ground barley	bushel		m^3		
Malt barley					
Beans - cull					
Bean screenings					
Dried beet pulp	bushel	19	m^3	235.1	49
Bone meal					
Brewer's grain	bushel	19	m^3	235.1	49
Bran - wheat	bushel	19	m^3	235.1	49
Corn meal	bushel	50	m^3	618.6	49
Fish meal	bushel	35	m^3	433.1	49
Linseed oil meal - solvent process					
Malt - dry ground					
Meat and bone scrap					
Beet molasses					
Cane or blackstrap molasses					
Corn sugar molasses					
Oat meal					
Ground oats	bushel	22	m^3	272.2	56
Rolled oats					
Peas (cull)					
Pea screenings					
Poultry-byproducts meal					
Rapeseed oil					
Rice bran	bushel	26	m^3	321.7	49
Safflower seed oil					
Safflower oil feed					
Safflower hulls (ground)					
Salt					
Silage					
Dried skimmed milk					
Tomato pomace (dried)					
Wheat germ					
Wheat flour					
Wheat-middlings					
Wheat-red dog					
Hay wafers			tonne	1000	

[1] Unless otherwise specified

TABLE 7.1.2 . Bulk Density, Specific Gravity and Freezing Points of Various Fruits and Vegetables.

Product	Bulk Density			Specific Gravity		Freezing Point		
	kg/m^3	lb/ft^3	(Ref)		(Ref)	°C	°F	(Ref)
FRUIT								
Apples	604	38.0	(56)	0.71-0.83	(53)	-2.8 to -1.3	27.0-29.7	(62)
Apricots	613	38.6				-1.7 to -1.2	28.9-29.9	(62)
Blackberries	609	38.3				-1.7	28.9	(74)
Cranberries	477	30.0	(21)			-1.3 to -0.9	29.7-30.3	(62)
Gooseberries						-1.1	30.0	(69)
Mulberries						-10.3 to -6.7	13.4-20.0	(74)
Raspberries	609	38.3				-1.2	29.9	(74)
Strawberries	609	38.3				-1.1 to -0.8	30.0-30.5	(62)
Cherries - with stern	715	45.0	(21)			-3.2 to -1.7	26.2-28.9	(62)
- without	810	51.0	(21)	1.078-1.092	(42)			
Grapes - (Vinifera)	370	23.3				-3.1 to -2.4	26.5-27.7	(62)
- (American)						-1.4	29.4	(62)
Peaches	613	38.6		0.99-1.01	(53)	-1.7 to -1.1	29.0-30.0	(62)
Pears	639	40.2	(56)	0.98-1.0	(53)	-3.1to -1.9	26.5-28.6	(62)
Plums	715	45.0		0.99-1.08	(53)	-3.1to -1.2	26.5-29.8	(62)
VEGETABLES								
Asparagus	574	36.1				-0.9 to -0.8	30.3-30.6	(62)
Beans - snap-green	763	48.0				-1.1to -1.0	30.0-30.2	(62)
- Lima	763	48.0				-0.6	30.9	(62)
Beets - red-topped	664	41.8				-1.9 to -1.0	28.6-30.2	(62)
- red-bunched	520	32.7				-1.4 to -1.0	29.5-30.2	(62)
Broccoli						-1.2 to -0.6	29.9-30.9	(62)
Brussel sprouts						-1.9	30.2	(62)
Cabbage	446	28.1				-1.1	30.0	(62)
Carrots - topped	639	40.2		1.015-1.036	(35)	-2.0 to -1.6	28.4-29.1	(62)
- bunched	550	34.6				-1.3	29.6	(74)
Cauliflower	319	20.1				-1.1to -0.9	30.0-30.4	(62)
Celery	527	33.2				-0.7 to -0.5	30.7-31.1	(62)
Corn - cob	445	28.0	(3)					
- shelled	712	44.8		1.096-1.116	(24)			
Cucumbers	613	38.6	(75)	0.89-1.00	(8)	-1.2 to -0.6	29.9-31.0	(62)
Eggplant	421	26.5				-0.9	30.3-30.4	(62)
Garlic						-3.2 to -0.9	26.3-30.3	(62)
Lettuce						-0.6 to -0.3	31.0-31.5	(62)
Melons- watermelon						0 to -0.4	30.3-31.2	(62)
-cantaloupe	610	38.4				-1.3	29.6	(62)
-honeydew	429	27.0				-1.2 to -1.1	29.8-30.0	(62)
Onions	639-728	40.2-45.8				-1.1to -1.0	30.0-30.2	(62)
Onions - green	272-	17.1-						
- bunched	298	18.8				-1.1	30.0	(62)
Parsnips	639	40.2				-1.4 to -0.8	29.5-30.1	(62)
Peas	390	24.1				-1.3 to -0.8	29.7-30.5	(62)
Peppers	319	20.1				-0.8	30.5	(62)
Potatoes- Katadhin				1.062-1.083	(29)	-2.0 to -0.9	28.4-30.4	(62)
- Chippewa	763	48.0		1.066-1.067	(29)	-2.0 to -0.9	28.4-30.4	(62)
- Green								
- Mountain				1.080-1.102	(29)	-2.0 to 0.9	28.4-30.4	(62)
- Kennebec/ Netted Gem				1.081-1.082	(29)	-2.0 to -0.9	28.4-30.4	(62)
Pumpkins						-1.2	29.9	(62)
Rutabaga	715	45.0				-1.3	29.7	(62)
Spinach	256	16.1				-0.4	31.3	(62)
Squash						-1.2 to -0.6	29.8-30.9	(62)
Tomatoes - ripe	677	42.6				-1.0 to -0.7	30.2-30.8	(62)
- mature green				0.970-0.991	(55)	-0.8	30.6	(62)
Turnips	690	43.4		0.940-0.959	(55)	-1.2 to -0.1	29.8-30.8	(62)
Radishes						-1.4	29.5	(74)
Sugar beets						-2.2 to -1.6	28.1-29.2	(73)

TABLE 7.1.3 Bulk Density and Specific Gravity of Seeds and Grains.

Product	Bulk Density			Specific Gravity	
	kg/m^3	lb/ft^3	(Ref)		(Ref)
Alfalfa	763	48.0	(3)	1.13-1.33	(3)
Barley	610	38.4	(3)		
Beans - Lima-dry	712	44.8	(3)		
- unshelled	407	25.6	(3)		
- snap	311	24.0	(3)		
Bluegrass	178 - 381	11.2-24.0	(3)		
Broom corn	559 - 635	35.2-40.0	(3)		
Brome grass					
Buckwheat	610 - 661	38.4-41.6	(3)	1.10	(3)
Castor beans	585	36.8	(3)		
Clover	763	48.0	(3)		
Corn - ear	445	28.0	(3)		
Corn -shelled	712	44.8	(3)	1.19	(3)
Fescue	712	44.8	(3)		
Flaxseed	712	44.8	(3)	1.10	(3)
Grain sorghum	610 - 636	38.4-40.0	(3)	1.22-1.26	(3)
Millet	610 - 636	38.4-40.0	(3)	1.11	(3)
Oats	407	25.6	(3)	0.95-1.06	(3)
Orchard grass	178	11.2	(3)		
Rapeseed	636 - 763	40.0-48.0	(3)		
Rice - rough	572	36.0	(3)	1.11	(3)
- smooth	715 - 763	45.0-48.0	(43)		
Rye	712	44.8	(3)	1.23	(3)
Sorgo	636	40.0	(3)		
Soybeans	763	48.0	(3)	1.13-1.18	(3)
Sunflower seed	305 - 407	19.2-25.6	(3)		
Timothy	572	36.0	(3)		
Vetch	763	48.0	(3)		
Walnuts	636	40.0	(3)		
Wheat	763	48.0	(3)	1.29-1.32	(3)
Peas	763	48.0	(3)	1.37[1]	(58)

[1] @ moisture content 12.9% w.b.

TABLE 7.1.4 Bulk Density, Specific Gravity and Freezing Points of Some Seeds, Grains, Feeds and Miscellaneous Materials.

Product	Bulk Density			Specific Gravity		Freezing Point	
	kg/m^3	lb/ft^3	(Ref)		(Ref)	°C	°F
NON-AGRICULTURAL MATERIALS							
Clay	1780 - 2574	112 - 162	(51)	1.8 -2.5	(64)		
Silt							
Sand - fine-dry	1430 - 1748	90 - 110	(37)	1.33 - 1.76	(36)		
- fine-wet	1748 - 1907	110 - 120	(37)	1.89 - 2.07	(36)		
- coarse-dry	1430 - 1748	90 - 110	(37)	1.44 - 1.76	(36)		
- coarse-wet	1748 - 1907	110 - 120	(37)	1.89 - 2.07	(36)		
Gravel	1907 - 2145	120 - 135	(37)	1.4 - 1.9	(36)		
Earth	1192 - 1430	75 - 90	(37)	1.2 - 1.5	(36)		
Coal - anthracite	826	52	(37)	1.4 - 1.7	(64)		
- bituminous	794	50	(37)	1.2 - 1.5	(47)		
Coke	365 - 508	23 - 32	(37)	0.4 - 0.6	(69)		

TABLE 7.1.4 Bulk Density, Specific Gravity and Freezing Points of Some Seeds, Grains, Feeds and Miscellaneous Materials.

Product	Bulk Density			Specific Gravity		Freezing Point	
	kg/m^3	lb/ft^3	(Ref)		(Ref)	°C	°F
NON-AGRICULTURAL MATERIALS							
Mud-soft flowing	1668 -1907	105 -120	(37)	1.92			
Peat	747	47	(36)	0.50	(64)		
Bentonite	779 - 810	49 -51	(22)				
Lime - hydrated	400 - 640	25 - 40	(78)				
- quick	770 - 1100	48 - 69	(78)				
- stone	2000 - 2800	125 -175	(78)				
PROCESSED FEEDS							
Alfalfa meal	254 - 350	16 - 22	(22)				
Barley - ground	381 - 413	24 - 26	(22)				
- malt	477 - 556	30 - 35	(22)				
Beans - cull	540 - 604	34 - 38	(22)				
- screening	540 - 604	34 - 38	(22)				
Beet pulp, dried							
Bone meal	779 - 842	49 - 53	(22)				
Brewer's grains	191 - 286	12 - 18	(22)				
Bran, wheat	159 - 254	10 - 16	(221				
Corn meal	445 - 508	28 - 32	(22)				
Fish meal	461 - 572	29 - 36	(22)				
Linseed oil meal	508 - 588	32 - 37	(22)				
Malt, dry-ground							
Meat and bone scrap	524 - 667	33 - 42	(22)				
Molasses - beet	191 - 215	12 - 13.5	(22)				
- cane or blackstrap	183 - 191	11.5- 12.0	(22)				
- corn sugar	- 191	12.0	(22)				
Oat meal	350 - 397	22 - 25	(22)				
Oats - ground	334 - 397	25	(22)				
- rolled	350 - 397	25	(22)				
Peas - cull	540 - 763	34 - 48	(22)				
- screenings	540 - 763	34 - 48	(22)				
Poultry-byproducts meal	524 - 667	33 - 42	(22)				
Rapeseed oil				0.913 -0.917	(41)	-7.5 to -6.7	18.5-20.0
Rice bran	159 - 254	10 -16	(22)				
Safflower seed oil meal	334 - 588	21 -37	(22)				
Safflower oil feed							
Safflower hulls ground							
Salt	953 - 1190	60 -75	(22)				
Skimmed milk, dried	381 - 540	24 -34	(22)	0.78 -1.25	(36)		
				2.1 -2.6	(41)		
Tomato pomace (dried)	191 - 302	12 -19	(22)				
Wheat germ	350 - 445	22 -28	(22)				
Wheat flour	413 - 477	26 -30	(22)				
Wheat middlings (shorts)	318 - 445	20 -28	(22)				
Wheat red dog	381 - 445	24 -28	(22)				
Hay wafers	318 - 397	20 -25	(21)				
Loose hay							
- in shallow mows	56 - 64	3.5 -4	(62)				
- in deep mows	72 - 79	4.5 -5	(62)				
Baled hay							
- field baled	127 - 222	8 -14	(62)				
- ordinary bales	159 - 238	10 -15	(62)				
- tight bales	191 - 318	12 -20	(62)				
Chopped hay							
- long (6.4 cm or more)	87- 127	5.5 -8.0	(62)				
- short (<6.4 cm)	127 -159	8.0 -10.0	(62)				

TABLE 7.1.5 Color, Odor and Texture of Some Processed Feeds (Ref 4).

Material	Color	Odor	Texture
Alfalfa meal	medium light green to dark green	freshly cut grass with slight caramel	fine
Ground barley	light grey to tannish grey	ground grain	fine
Malt barley	greyish tan	sweet ground barley and malt	
Beans - cull	cream to off-white	ground grain	fine
- screenings	cream	ground grain	fine
Dried beet pulp			
Bone meal	tan to greyish tan	cooked meat and bones	fine
Brewer's grains	greyish tan	dried fermented grain	fine
Bran (wheat)	light tan to reddish grey	bland	fine
Bentonite	cream to pale brown	odorless	very fine
Corn meal	greyish yellow to light yellow	finely ground corn	fine
Fish meal	light tan to reddish brown	cooked fish	fine
Linseed oil meal (solvent process)	greyish brown	ground whole flaxseed	fine
Malt (dry ground)			
Meat and bone scrap	light brown to medium dark brown	cooked meat and tallow	fine
Beet molasses	brown to very dark brown	sulfur-like	
Cane or blackstrap molasses	brown to very dark brown	cooking molasses	
Corn sugar molasses	brown to very dark brown	corn syrup	
Oat meal	light grey or greyish white	rolled oats	fine
Ground oats	light grey to tannish grey	ground grain	fine
Rolled oats	tan to greyish white	cooked cereal	flaky
Peas - cull	light whitish tan	ground corn	fine
- screenings	light tan	ground corn	fine
Poultry byproducts meal	light brown to brown	meat scraps	fine
Rapeseed oil			
Rice bran	tan to brown	wheat	fine
Safflower seed oil meal	dark brown	corn oil meal	fine
Safflower oil feed	dark brown to brown	corn oil meal	fine
Safflower hulls (ground)	light grey	odorless	fine
Salt	white	odorless	fine
Dried skimmed milk	off white to light cream	milk	fine
Tomato pomace (dried)	Brown and orange mixture	dried tomatoes	fine
Wheat germ	light yellow	green plant material	fine
Wheat flour	white		very fine
Wheat middlings	tannish grey to light brown	bland-ground wheat	fine
Wheat red dog	light tannish white	ground wheat	fine

TABLE 7.1.6 Color and Surface Texture of Various Fruits, Vegetables and Grains.

Product or Material	Color	Surface Texture
FRUIT		
Apples		
- Jonathon	uniform bright red	smooth
- McIntosh	medium red	smooth
- Golden Delicious	yellow	smooth
- Red Delicious	medium red	smooth
- Northern Spy	bright striped red	smooth
- Rome Beauty	medium red	smooth
- Winesap	dark uniform red	smooth
Apricots	golden yellow - with red blush	regular surface, fuzzy
Berries		
- Blackberries	black	smooth
- Cranberries	bright to dark red	smooth
- Gooseberries	greenish - occasional red	smooth
- Raspberries - red	bright red	
- black	black to glossy black	
- Strawberries	red	
Cherries	bright to dark red	smooth
Grapes	green, purple	smooth
Peaches	light medium blush, bright red blush	regular surface, fuzzy
Pears	green, greenish yellow, yellow	irregular surface
Plums	yellowish green, purplish blue, black or reddish	smooth
VEGETABLES		
Asparagus	green or white	
Beans - green or snap	green or yellow	fine grained - smooth
- lima	green to dark green	
Beets - red	dark red - wine	
Broccoli	dark green to purplish green	
Brussel sprouts	green	
Cabbage - early	yellow green to greenish grey	smooth
- late	medium to yellow green	smooth
Carrots	deep orange	
Cauliflower	white	
Celery	green; occasional white or yellow	
Corn - sweet	white or yellow	
- fint	deep golden yellow to pearly white	
- dent	creamy white, deep yellow	
Cucumbers	dark green	smooth or warted
Eggplant	dark purple	smooth
Garlic	red or white	
Lettuce	green	
Watermelon	solid green to striped grey	smooth
Cantaloupe	tan	pebbly surface
Honeydew melon	whitish green to creamy yellow	smooth
Onions	white, yellow or reddish brown	
Onions - green	green leaves, white neck	
Parsnips	white	smooth
Peas	green	smooth
Peanuts	tan	
Peppers	green, red, yellow	smooth
Potatoes- Katandin	dark cream - buff	smooth, few shallow eyes
- Chippewa	dark cream - buff	smooth, shallow eyes
- Green Mountain	white	smooth, often netted, medium deep eyes
- Cobbler	creamy, white	smooth, shallow to deep eyes
- Sweet	yellowish fawn, whitish to reddish	
Pumpkins	reddish - orange	smooth
Rutabaga		
Spinach	green	
Squash	green	
Tomatoes	bright red	smooth

TABLE 7.1.6 Color and Surface Texture of Various Fruits, Vegetables and Grains.

Product or Material	Color	Surface Texture
VEGETABLES		
Turnips	brown	
Radishes	dark red or white	smooth
Sugar beets	yellowish brown	
GRAINS AND SEEDS		
Alfalfa	greenish yellow or light brown	
Barley		
Lima beans - dry		
Blue grass	yellow	smooth
Bromegrass (smooth)	brown	fibrous surface
Buckwheat		
Castor beans		
Clover		
Corn - shelled	yellow	
Fescue (meadow)	brown	
Flaxseed		smooth and shiny
Grain sorghum	white, yellow, red, pink	
Millet	whitish	smooth
Oats		
Rapeseed		
Rice - rough- smooth	white	smooth
Rye		
Sorgo		
Soybeans		
Sunflower seeds	shell-black and white	
Timothy	whitish	smooth
Vetch		smooth
Wheat	cream to yellowish, light brown to darker shades of red	

TABLE 7.1.7 The Shapes and Sizes of Various Agricultural Products.

Product or Material	Shape	Size
FRUIT		
Apples (Ref 53)		
- Jonathon	round to round conic	68 x 66 x 49 mm
- McIntosh	roundish oblate	68 x 66 x 49 mm
- Golden Delicious	conical	70 x 68 x 56 mm
- Red Delicious	oblong conic	77 x 72 x 64 mm
- Northern Spy	roundish conical	77 x 72 x 64 mm
- Rome Beauty	round to oblate	80 x 74 x 59 mm
- Winesap	conical	medium to below medium
Apricots	divided oblate spheroid	
Berries		
- Blackberries	ovate	
- Canberries	round	
- Gooseberries	round to pear shaped	medium to large
- Raspberries	round to conic	large
- Strawberries	round, blunt, or long conic	
Cherries	round	
Grapes	round	
Peaches	oblate spheroid	medium to large
Plums	divided oblate spheroid	

TABLE 7.1.7 The Shapes and Sizes of Various Agricultural Products.

Product or Material	Shape	Size
VEGETABLES		
Asparagus	stalks	
Beans-green		
Beans-Lima		
Beets		
Broccoli	stalks	
Brussel sprouts	round	
Cabbage - early	heads-round, flattened and pointed	150 - 200 mm long; 110 - 240 mm diam. (6 - 8 in. long; $4^1/_2$ -$9^1/_2$ in. diam.)
- late	heads-round, slightly flattened	140 - 200 mm long; 150 - 280 mm diam. ($5^1/_2$ - 8 in. long; 6 - 11in. diam.)
Carrots	long conic	
Cauliflower		
Celery	stalks	
Corn		
- popcorn		
- sweet		
- soft		
- flint		250 - 330 mm long; circumference 110 - 150 mm (10 - 13 in. long; circumference $4^1/_2$ - 6 in.)
- dent		170 - 230 mm long; circumference 160 - 190 mm ($6^1/_2$ - $9^1/_2$ in. long; circumference $6^1/_2$ - $7^1/_2$ in.)
Cucumbers		
Eggplant		large to medium
Garlic		
Lettuce		
Watermelon		
Cantaloupe	oval, elongated or roundish	
Honeydew	bluntly oval	150 - 200 mm diam; 200 - 250 mm long (6 - 8 in. diam; 8 - 10 in. long)
Onions	globular or oval	
Onions-green		
Parsnips		
Peas	spherical	
Peanuts		
Peppers		
Potatoes		
- Katadhin		
- Chippewa		
- Green Mountain		
- Cobbler		
- Sweet		
Pumpkins		
Rutabaga		
Spinach	leaves-oval to halberd	
Squash		
Tomatoes	round, oblate or globular	
Turnips		
Radishes		
Sugar beets		
GRAIN AND SEEDS		
Alfalfa (Ref 53)	oval to kidney	2.4 x 2.0 x 1.0 mm (0.09 x 0.06 x 0.04 in.)
Barley (Ref 53)	elliptic	10.4 x 3.5 x 2.7 mm (0.41 x 0.14 x 0.11in.)
Lima beans-dry		
Snap beans		
Blue grass	elongated truncate	5.6 x 2.5 x 1.9 mm (0.22 x 0.10 x 0.07 in.)
Bromegrass	flattish	10.5 x 1.5 mm (0.4 x 0.05 in.)

TABLE 7.1.7 The Shapes and Sizes of Various Agricultural Products.

Product or Material	Shape	Size
GRAIN AND SEEDS		
Buckwheat	sharp-edged triangular	7.0 x 5.0 mm (0.3 x 0.2 in.)
Castor beans	obovoid	granular 3.2 to 12.7 mm ($^1/_8$ to ½ in.)
Clover (Ref 53)		1.7 x 1.3 x 1.0 mm (0.07 x 0.05 x 0.04 in.)
Corn-shelled (Ref 53)		16.3 x 20.3 x 12.7 mm (0.64 x 0.80 x 0.50 in.)
Fescue	elongated	5.0 x 1.0 mm (0.2 x 0.04 in.)
Flaxseed (Ref 53)	flattish, elliptic ovate	4.9 x 2.3 x 1.0 mm (0.19 x 0.09 x 0.04 in.)
Grain sorghum		
Millet	ellipsoid	
Oats (Ref 53)	elongated	12.9 x 2.9 x 2.3 mm (0.51 x 0.11 x 0.09 in.)
Orchard grass	elongated	5 x 15 x 1 mm (0.19 x 0.58 x 0.04 in.)
Rapeseed	spheroid	2 to 3 mm 8.5 x 3.5 x 2.3 mm
Rice		(0.33 x 0.12 x 0.09 in.)
Rye		fine (100 mesh to 3.2 mm) ($^1/_8$ in.)
Sorgo		
Soybeans	compressed oval to spheroid	
Sunflower seeds		16.5 x 9.1 x 3.6 mm (0.65 x 0.36 x 0.14 in.)
Timothy	elongated ellipsoid	
Vetch	round	
Wheat	ovate, elliptical	6.6 x 3.2 x 3.1 mm (0.26 x 0.13 x 0.12 in.)
Peas		granular 3.2 mm to 12.7 mm (⅛ to ½ in.)

TABLE 7.1.8 Fineness Modulus and Uniformity Index of Some Seeds, Grains and Grain Products.

Product	Fineness Modulus	(Ref)	Uniformity Index	(Ref)
Barley	3.69 - 5.00	(66)	10.0.0	
Corn-shelled	2.50 - 6.00	(66)	10.0.0	
Grain sorghum	5.5	(28)	10.0.0	(28)
Oats	3.52 - 4.50	(66)	10.0.0	
Soybeans	6.00	(66)	10.0.0	
Wheat	2.94 - 5.00	(66)	10.0.0	
Flour	0.00	(39)	10.0.0	

7.1.4 Tables Of Mechanical Properties.

TABLE 7.1.9 Friction Coefficients of Various Seeds and Grains.

Products	Material Acted Upon	Coefficients Friction (Moisture Content on Wet Basis)							
			(Ref)		(Ref)		(Ref)		(Ref)
		Moisture		Moisture		Moisture			
Alfalfa		82.0% wb		33.3% wb		22.2% wb			
	Concrete (plastic smooth finish)	0.737		0.478		0.328			
	Concrete (steel trowel finish)	0.686		0.562		0.649			
	Concrete (wood float finish)	0.775		0.714		0.655			
	Oak (grain parallel)	0.610		0.373		0.310			
	Oak (grain perpendicular)	0.674		0.478		0.333			
	Douglas fir (grain parallel)	0.697	(21)	0.393	(21)	0.334	(21)		
	Douglas fir (grain perpendicular)	0.614		0.448		0.374			
	Plastic (Teflon)	0.191		0.179		0.160			
	Plastic (Polyethylene)	0.610		0.394		0.320			
	Mild steel (cold rolled)	0.653		0.510		0.458			
	Galvanized sheet metal	0.535		0.374		0.359			
Barley		Moisture		Moisture		Moisture		Moisture	
		10.7%		12.3%		14.3%		16.4%	
	Concrete (plastic smooth finish)	0.232		0.248		0.236		0.331	
	Concrete (steel trowel finish)	0.557		0.547		0.568		0.619	
	Concrete (wood float finish)	0.503		0.522		0.508		0.552	
	Oak (grain parallel)	0.234		0.214		0.205		0.304	
	Oak (grain perpendicular)	0.285	(21)	0.277	(21)	0.277	(21)	0.330	(21)
	Douglas fir (grain parallel)	0.269		0.275		0.297		0.374	
	Douglas fir (grain perpendicular)	0.322		0.306		0.323		0.412	
	Plastic (Teflon)	0.169		0.147		0.131		0.105	
	Plastic (Polyethylene)	0.232		0.275		0.278		0.354	
	Mild steel (cold rolled)	0.197		0.247		0.288		0.214	
	Galvanized sheet metal	0.198		0.174		0.204		0.342	
Beans (Lima, snap)	Self	0.50	(32)						
	Smooth wood	0.42	(32)						
	Steel	0.37	(32)						
	Smooth concrete	0.44	(32)						
Corn (ear)	Smooth wood	0.62	(62)						
		Moisture		Moisture		Moisture		Moisture	
Corn (shelled)		7.5% wb		9.9% wb		12.2% wb		13.9% wb	
	Concrete (plastic smooth finish)	0.268		0.247		0.331		0.345	
	Concrete (steel trowel finish)	0.405		0.589		0.677		0.635	
	Concrete (wood float finish)	0.456	(21)	0.615	(21)	0.647	(21)	0.540	(21)
	Oak (grain parallel)	0.238		0.282		0.261		0.294	
	Oak (grain perpendicular)	0.245		0.313		0.291		0.360	
	Douglas fir (grain parallel)	0.271		0.314		0.330		0.365	
	Douglas fir (grain perpendicular)	0.288		0.314		0.333		0.380	
	Plastic (Teflon)	0.170	(21)	0.176	(21)	0.160	(21)	0.123	(21)
	Plastic (Polyethylene)	0.219		0.270		0.303		0.381	
	Mild steel (cold rolled)	0.225		0.201		0.201		0.238	
	Galvanized sheet metal	0.195		0.241		0.246		0.372	
Fescue									
Flaxseed	Self	0.45							
	Smooth wood	0.40							
	Steel	0.33	(32)						
	Smooth concrete	0.41							
Grain sorghum	Self	0.65							
	Smooth wood	0.30	(65)						
	Steel	0.372							
	Smooth concrete	0.33							
Millet									

TABLE 7.1.9 Friction Coefficients of Various Seeds and Grains.

Products	Material Acted Upon	Coefficients Friction (Moisture Content on Wet Basis)							
			(Ref)		(Ref)		(Ref)		(Ref)
Oats		Moisture 10.6% wb		Moisture 13.0% wb		Moisture 14.0% wb		Moisture 16.0% wb	
	Concrete (plastic smooth finish)	0.276		0.343		0.326		0.292	
	Concrete (steel trowel finish)	0.396		0.443		0.514		0.459	
	Concrete (wood float finish)	0.434	(21)	0.435	(21)	0.423	(21)	0.456	(21)
	Oak (grain parallel)	0.202		0.244		0.232		0.314	
	Oak (grain perpendicular)	0.231		0.251		0.248		0.307	
	Douglas fir (grain parallel)	0.268		0.289		0.343		0.371	
	Douglas fir (grain perpendicular)	0.294		0.354		0.358		0.366	
	Plastic (Teflon)	0.130		0.139		0.126		0.110	
	Plastic (Polyethylene)	0.204	(21)	0.239	(21)	0.278	(21)	0.312	(21)
	Mild steel (cold rolled)	0.197		0.256		0.214		0.204	
	Galvanized sheet metal	0.223		0.240		0.180		0.405	
Orchard grass									
Rapeseed									
		Moisture							
Rice (rough)		14% wb							
- Blue Rose	Flat galvanized iron Concrete	0.402 -0.414							
	Concrete (smooth finish)	0.516 -0.531							
	Wood (plywood, across grain)	0.495 -0.500							
	Wood (plywood, with grain)	0.435 -0.440							
	Wood (cribbed wall)	0.583 -0.613							
- Rexoro	Flat galvanized iron	0.447 -0.449	(44)						
	Concrete (smooth finish)	0.561 -0.423							
	Plywood (across grain)	0.530 -0.542							
	Plywood (with grain)	0.500 -0.506							
Rice (rough)	Self	0.73	(62)						
	Smooth wood	0.44	(62)						
	Steel	0.41	(62)						
	Smooth concrete	0.52	(62)						
Rice (smooth)									
		Moisture							
Rye		14% wb							
	Self	0.49	(37)						
	Smooth wood	0.406	(37)						
	Steel	0.35	(37)						
	Smooth concrete	0.33	(37)						
Sorgo									
		Moisture		Moisture		Moisture		Moisture	
Soybeans		7.1% wb		8.1% wb		9.8% wb		12.2% wb	
	Concrete (plastic smooth finish)	0.246		0.318		0.308		0.363	
	Concrete (steel trowel finish)	0.390		0.554		0.467		0.552	
	Concrete (wood float finish)	0.391		0.515		0.367		0.515	
	Oak (grain parallel)	0.239		0.294		0.281		0.279	
	Oak (grain perpendicular)	0.337	(21)	0.336	(21)	0.308	(21)	0.360	(21)
	Douglas fir (grain parallel)	0.290		0.323		0.333		0.353	
	Douglas fir (grain perpendicular)	0.309		0.366		0.314		0.441	
	Plastic (Teflon)	0.160		0.174		0.155		0.147	
	Plastic (Polyethylene)	0.246		0.316		0.288		0.430	
	Mild steel (cold rolled)	0.191		0.192		0.202		0.230	
	Galvanized sheet metal	0.206		0.205		0.182		0.199	
Sunflower seeds									
Tares	Self	0.55	(32)						
	Smooth wood	0.42	(32)						
	Steel	0.36	(32)						
	Smooth concrete	0.39	(32)						

TABLE 7.1.9 Friction Coefficients of Various Seeds and Grains.

Products	Material Acted Upon	Coefficients Friction (Moisture Content on Wet Basis)							
			(Ref)		(Ref)		(Ref)		(Ref)
		Moisture		Moisture		Moisture		Moisture	
Timothy		16.7% wb		30.5% wb		38.1% wb		79.3% wb	
	Concrete (plastic smooth finish)	0.270		0.323		0.462		0.584	
	Concrete (steel trowel finish)	0.446		0.480		0.586		0.598	
	Concrete (wood float finish)	0.629	(21)	0.731	(21)	0.777	(21)	0.765	(21)
	Oak (grain parallel)	0.347		0.441		0.514		0.521	
	Oak (grain perpendicular)	0.423		0.382		0.560		0.532	
	Douglas fir (grain parallel)	0.398		0.417		0.534		0.637	
	Douglas fir (grain perpendicular)	0.439		0.522		0.637		0.594	
	Plastic (Teflon)	0.215		0.192		0.191		0.226	
	Plastic (Polyethylene)	0.213		0.383		0.517		0.661	
	Mild steel (cold rolled)	0.315		0.388		0.427		0.570	
	Galvanized sheet metal	0.318		0.483		0.320		0.526	
Vetch	Self	0.470							
	Smooth wood	0.372	(62)						
	Steel	0.242							
	Smooth concrete	0.255							
Walnuts									
		Moisture		Moisture		Moisture		Moisture	
Wheat		11.2% wb		13.0% wb		15.0% wb		15.7% wb	
	Concrete (plastic smooth finish)	0.356		0.460		0.503		0.563	
	Concrete (steel trowel finish)	0.516		0.520		0.547		0.677	
	Concrete (wood float finish)	0.506	(21)	0.546	(21)	0.510	(21)	0.689	(21)
	Oak (grain parallel)	0.235		0.247		0.353		0.411	
	Oak (grain perpendicular)	0.264		0.291		0.368		0.464	
	Douglas fir (grain parallel)	0.307		0.345		0.468		0.482	
	Douglas fir (grain perpendicular)	0.347		0.382		0.457		0.501	
	Plastic (Teflon)	0.170		0.156		0.146		0.119	
	Plastic (Polyethylene)	0.269	(21)	0.351	(21)	0.389	(21)	0.448	(21)
	Mild steel (cold rolled)	0.204		0.286		0.269		0.514	
	Galvanized sheet metal	0.095		0.142		0.272		0.332	
Sudan grass									
Peas	Self	0.47	(32)						
	Smooth wood	0.28	(32)						
	Steel	0.26	(32)						
	Smooth concrete	0.29	(32)						
		Moisture							
Corn silage		78.4% wb							
	Concrete (plastic smooth finish)	0.456							
	Concrete (steel trowel finish)	0.560							
	Concrete (wood float finish)	0.699							
	Oak (grain parallel)	0.583							
	Oak (grain perpendicular)	0.563							
	Douglas fir (grain parallel)	0.567	(21)						
	Douglas fir (grain perpendicular)	0.581							
	Plastic (Teflon)	0.184							
	Plastic (Polyethylene)	0.401							
	Mild steel (cold rolled)	0.569							
	Galvanized sheet metal	0.493							
Grass silage	Steel	0.700	(3)						
		Moisture		Moisture					
Hay (alfalfa-grass mixture) chopped length		10% wb 43 mm		11.2% wb 10 mm					
	Steel	0.400	(62)	0.396	(62)				
	Smooth wood	0.454	(62)	0.380	(62)				

TABLE 7.1.9 Friction Coefficients of Various Seeds and Grains.

Products	Material Acted Upon	Coefficients Friction (Moisture Content on Wet Basis) (Ref)	(Ref)	(Ref)	(Ref)
Apples					
- Delicious	Wood	*Coefficient of Friction*			
		Kinetic	*Static*		
	metal	0.33	0.37		
	ethafoam	0.29	0.40		
	plastic foam	0.60	0.72		
	canvas	0.28	0.36		
- McIntosh	Wood	0.29	0.36		
	metal	0.28	0.38		
	ethafoam	0.33	0.38		
	plastic foam	0.64	0.80		
	canvas	0.27	0.38		
Tomatoes	Wood	0.42	0.43		
	metal	0.31	0.36		
	ethafoam	0.48	0.47		
	plastic foam	0.71	0.74		
	canvas	0.49	0.50		

TABLE 7.1.10 Friction Coefficients Of Some Non-agricultural Materials (Ref 37, except as noted).

Material		Coefficients of Friction			
		On Self	On Smooth Wood	On Steel	On Concrete
Clay				0.60-0.70 (47)	
Silt					
Sand	- dry	0.674	0.577	0.324	0.577
	- wet				
Gravel					
Earth			0.25-1.00		
Peat					
Coal	- anthracite	0.509	0.466	0.286	0.509
	- bituminous	0.700	0.700	0.324	0.700
Coke			0.834	0.466	0.839

TABLE 7.1.11 Dielectric Constants Of Various Seeds And Grains At 24°C.

Grain	Moisture Content %)	Dielectric Constant 10 MHz	40 MHz	(Ref)
Alfalfa				
- DuPuits	8.1	- -	3.3	(54)
- Ladak	8.3	- -	3.6	(54)
- Narrangansett	9.8	- -	3.7	(54)
	6.2	- -	3.2	(54)
	2.7	- -	2.6	(54)
Clover				
- Alsike	8.0	- -	3.2	(54)
- Ladino	7.1	- -	3.2	(54)
	5.7	- -	3.0	(54)
	2.3	- -	2.8	(54)
- red, Pennscott	7.4	- -	3.1	(54)
	6.0	- -	2.9	(54)
	2.5	- -	2.7	(54)
- white Dutch	8.1	- -	3.1	(54)
Corn				
- shelled	7.4	3.6		(26)
	11.0	4.2		(26)
	13.0	4.5		(26)
- yellow, dent	13.7	- -	4.2	(54)
	8.3	- -	3.3	(54)
Millet - German	9.8	3.2	3.1	(54)
	11.4	3.9	3.7	(54)
Oats				
- spring-Missouri 0.205	8.1	2.4	2.3	(54)
	12.4	2.9	2.7	(54)
- winter-DuBois	10.7	- -	2.6	(54)
Rice	10.0	3.8		(26)
	16.0	3.8		(26)
	19.0	4.3		(26)
Rye - winter, Balbo	12.7	- -	4.0	(54)
Wheat	8.9	4.0		(26)
	11.2	4.7		(26)
	13.6	5.2		(26)
Rapeseed oil		2.85 [1]		

[1] @18.1 C, 3 MHZ

TABLE 7.1.12 Heats Of Respiration Of Fruits And Vegetables.

Product	J / (h·kg °C)			BTU / (24 hr·ton °F)			(Ref)
	@ 0°C	@ 4°C	@ 16°C	@ 32°F	@ 40°F	@ 60°F	
FRUIT							
Apples	72.45	125.3	443	830	1,435	5,075	(60)
Cranberries	57.61	80.31		660	920		(60)
Gooseberries							
Mulberries	87.29[1]			1,000[1]			
Raspberries							
- red	480.1[2]		1,440	5,500[2]		16,500	
- black							
Strawberries	285.0	452.2	1,568	3,265	5,180	17,960	(60)
Cherries							
- sweet	109.1			1,250			(60)
- sour							
Grapes							
- Vinifera	31.86		210.4	365		2,410	(60)
- American	52.55	102.1	304.4	602	1,170	3,487	(60)
Peaches	96.89	151.5	723.2	1,110	1,735	8,285	
Pears	67.22		960.2	770		11,000	(60)
Plums	47.14	104.8	227	540	1,200	2,600	(60)
VEGETABLES							
Asparagus	724.5	1,222	2,793	8,300	14,000	32,000	
Beans - snap	413.8	585.2		4,740	6,704		
- Lima	203.4 to 261.9	375.4 to 523.8	1,920 to 2,393	2,330 to 3,000	4,300 to 6,000	21,990 to 27,410	
Beets - red-topped	101.8	158.9		1,166	1,820		
Broccoli		1,309			15,000		
Brussel sprouts	288.1 to 724.5	576.1 to 960.2	1,152 to 2,400	3,300 to 8,300	6,600 to 11,000	13,200 to 27,500	(5)
Cabbage	104.6	145.8	356.2	1,200	1,670	4,080	(60)
Carrots							
- topped	185.9	302.9	705.3	2,130	3,470	8,080	(60)
Cauliflower		392.8	881.7		4,500	10,100	(5)
Celery	246.2	396.3		2,820	4,540		
Corn - green	514.2	714.9		5,890	8,190		
- dried							
Cucumbers	147.5	222.6	913.1	1,690	2,550	10,460	(60)
Eggplant							
Garlic							
Lettuce	55.69	645.3		638	7,392		
Melons							
- watermelon							
- cantaloupe		326.5	705.3		3,740	8,080	
- honeydew		78.56	270.6		900	3,100	(60)
Onions	76.28	163.2[3]		880	1,870[3]		
Onions-green, bunched							
Parsnips							
Peas-green	721	1,276	3,656	8,260	14,620	41,880	(60)
Peanuts							
Peppers		132.5			1,518		
Potatoes	57.61	124.8		660	1,430		(60)
Pumpkins							
Rutabaga							
Spinach	397.2	831.9	3,286	4,550	9,530	37,640	(60)
Squash							
Tomatoes							
- ripe	89.04	110	492.3	1,020	1,260	5,640	(60)
- mature green	50.63	93.4	543.8	580	1,070	6,230	(60)
Turnips	5.76	49.93		66	572		
Radishes							
Sugar beet							

[1] @ 2°C (@ 35°F) [2] @ 2°C (@ 36°F) [3] @ 10°C (@ 50°F)

TABLE 7.1.13 Latent Heats And The Rate Of CO_2 Production Of Some Agricultural Products At Recommended Storage Temperatures.

Product	Latent Head		Rate of CO_2 Production	
	kJ / kg	BTU / lb (Ref 5)	L / (kg·d)	ft^3 / (ton·day) (Ref 31)
FRUIT				
Apples	281	121	0.05	1.5
Apricots	284	122		
Berries - blackberries	284	122	0.24 - 0.27	7.7- 8.6
- cranberries	288	124		
- gooseberries	293	126		
- raspberries-black	284	122	0.27 - 0.43	8.6 - 13.9
-red	281	121		
- strawberries	300	129	0.20	6.4
Cherries	279	120		
Grapes - American	270	116	0.06	2.0
- Vinifera	270	116		
Peaches	288	124	0.09	3.0
Pears	274	118	0.03 - 0.05	1.1 - 1.5
Plums	286	123	0.09	3.0
VEGETABLES				
Asparagus	312	134	0.40	12.9
Beans-green	298	128		
Beets	293	126	0.07 - 0.10	2.4 - 3.2
Broccoli	302	130		
Brussel sprouts	284	122	0.22 - 0.34	6.9 - 10.8
Cabbage - early			0.13 - 0.19	4.3 - 6.0
- late	307	132	0.11 - 0.17	3.6 - 5.4
Carrots	293	126	0.05 - 0.09	1.5 - 3.0
Cauliflower	307	132	0.11 - 0.34	3.4 - 10.8
Celery	314	135	0.07 - 0.10	2.1 - 3.2
Corn - sweet-shelled	247	106		
- popcorn	44	19		
Cucumbers	319	137		
Eggplant	307	132		
Garlic - dry	247	106		
Lettuce	316	136	0.15 - .24	4.7- 7.7
Melons - cantaloupe	307	132		
- honeydew	307	132		
- watermelon	307	132		
Onions	288	124	0.22 - 0.25	6.9 - 8.1
Onions-green, bunched	293	126	0.13 - 0.23	4.3 - 7.3
Parsnip	261	112	0.16 - 0.22	5.1 - 6.9
Peas	247	106	0.40 - 0.51	12.9 - 16.3
Peppers	307	132		
Potatoes - early	270	116	0.12	4.0
- late	258	111		
Rutabaga	295	127		
Spinach	307	132	0.16 - 0.29	5.1 - 9.4
Squash - summer	314	135		
- winter	295	127		
Sweet potatoes	226	97		
Tomato - green mature	312	134	0.20 - 0.29	6.4 - 9.4
- ripe	312	134		
Turnips	302	130	0.05 - 0.08	1.7 - 2.6

TABLE 7.1.14 Specific Heats Of Fruits And Vegetables (Ref 30, 4, unless otherwise noted).

Product or Materials	Specific Heats above freezing J / (kg·°C)	above freezing BTU / (lb °F)	below freezing J / (kg °C)	below freezing BTU / (lb °F)	(Ref)
FRUITS					
Apples	3600	0.86	1880	0.45	
Apricots	3680	0.88	1930	0.46	
Blackberries	3680	0.88	1930	0.46	
Cranberries	3770	0.90	1930	0.46	
Gooseberries	3770	0.90	1930	0.46	
Raspberries	3560	0.85	1880	0.45	
Strawberries	3850	0.92	1970	0.47	
Cherries	3640	0.87	1880	0.45	
Grapes	3600	0.86	1840	0.44	
Peaches	3770	0.90	1930	0.46	
Pears	3600	0.86	1880	0.45	
Plums	3680	0.88	1880	0.45	
VEGETABLES					
Asparagus	3940	0.94	2010	0.48	
Beans - snap	3810	0.91	1970	0.47	
- Lima	3060	0.73	1670	0.40	
Beets	3600	0.86	1970	0.47	
Broccoli	3850	0.92	1970	0.47	
Brussel sprouts	3680	0.88	1930	0.46	
Cabbage	3940	0.94	1970	0.47	
Carrots	3600	0.86	1880	0.45	
Cauliflower	3890	0.93	1970	0.47	
Celery	3980	0.95	2010	0.48	
Corn	3350	0.80	1800	0.43	
Cucumbers	4060	0.97	2050	0.49	
Eggplant	3940	0.94	2050	0.49	
Garlic	3310	0.79	1760	0.42	(62)
Lettuce	4020	0.96	2010	0.48	
Melons - watermelon	4060	0.97	2010	0.48	
- cantaloupe	3940	0.94	2010	0.48	
- honeydew	3940	0.94	2010	0.48	
Onions	3810	0.91	1930	0.46	
Onions-green, bunched	3810	0.91	1930	0.46	
Parsnips	3520	0.84	1930	0.46	
Peas	3310	0.79	1760	0.42	
Peppers	3940	0.94	1970	0.47	
Potatoes	3430	0.82	1800	0.43	
Sweet potato	3140	0.75	1670	0.40	
Pumpkins	3850	0.92	1970	0.47	
Rutabaga	3810	0.91	1970	0.47	(62)
Spinach	3940	0.94	2010	0.48	
Squash	3850	0.92	1970	0.47	
Tomatoes	3980	0.95	2010	0.48	
Turnips	3890	0.93	1670	0.40	
Radishes	3980	0.95	2010	0.48	
Sugar beet					
MISCELLANEOUS					
Salt	1760-1840	0.42-0.44[1]	----		(23)
Flour	1590	0.38[2]	1170	0.28	(23)

[1] moist. content 10.5-13.5%

[2] moist. content 13.5%

TABLE 7.1.15 Specific Heats Of Grains And Seeds.

Product or Material	Moisture Content (% w.b.)	Temperature Range		Specific Heat		(Ref) °C
		°C	°F	J/(kg.°C)	BTU/(lb.°F)	
Barley	9.4			1500	0.359	(18)
	13.8			1620	0.387	(18)
	16.5			1830	0.436	(18)
Corn	0.91	12 - 29	54.0 - 83.8	1530	0.366	(34)
	5.08	12 - 29	54.0 - 83.8	1690	0.404	(34)
	9.81	12 - 29	54.0 - 83.8	1830	0.438	(34)
	14.7	12 - 29	54.0 - 83.8	2030	0.484	(34)
	20.1	12 - 29	54.0 - 83.8	2220	0.531	(34)
	24.7	12 - 29	54.0 - 83.8	2370	0.567	(34)
	30.2	12 - 29	54.0 - 83.8	2460	0.588	(34)
Oats	0			1280	0.305	(34)
Rice	0			1110	0.265	(34)
Rice-rough (Italian origin)	10.2			1580	0.378	(18)
	13.5			1680	0.402	(18)
	17.0			1880	0.450	(18)
Rice - fully finished						
- (Italian origin)	10.8			1590	0.380	(18)
	14.6			1720	0.411	(18)
	17.4			1840	0.440	(18)
Soybeans	17.7	24 - 54	75.0 - 129	1970	0.470	(34)
	21.7	23 - 88	73.0 - 190	2050	0.490	(34)
Wheat	0.4			1260	0.302	(26)
	8.3			1440	0.343	(26)
	9.2	26 - 49	79.0 - 120	1550	0.370	(34)
	13.0			1580	0.377	(26)
	33.6			2440	0.582	(26)
Alfalfa						
Beans - Lima-dry						
- Lima-unshelled						
- snap						
Bluegrass						
Broom corn						
Brome grass						
Buckwheat						
Castor beans						
Miscellaneous						
Clay		21 - 24	69.8 - 75.2	940	0.224	(4)
Coke				1110	0.265	(4)
Salt				1130 - 1340	0.27 - 0.32	(13)

TABLE 7.1.16 Terminal Velocities Of Some Grains, Seeds And Fruits.

Product	Terminal Velocity		
	m/s	ft/sec	(Ref)
GRAINS AND SEEDS			
Alfalfa	5.5	17.9	(7)
Barley	7.0	23.0	(7)
Corn-shelled	10.6	34.9	(7)
Flaxseed	4.7	15.3	(7)
Oats-small	5.9	19.3	(7)
-large	6.3	20.8	(7)
Soybeans	13.5	44.3	(7)
Wheat	9.0	29.5	(7)
FRUIT			
Apples - McIntosh	40.4	132.5	(59)
- Jonathon	38.5	126.3	(59)
- Northern Spy	41.2	135.0	(50)
- Cortland	41.3	135.5	(59)
Apricots- Montgamet	31.8	104.2	(59)
Blueberries-Jersey	17.5	57.5	(59)
Cherries- Montmorency	22.6	74.0	(59)
Cranberry	9.7	31.8	(78)
Grape	15.2	49.8	(78)
Peaches-Elberta	41.5	136.0	(59)
-Red Haven	40.9	134.3	(59)
Plums-Stanley prune	31.9	104.8	(59)
Potatoes	26.8	88.0	(78)

TABLE 7.1.17 Modulus Of Elasticity Of Some Varieties Of Apples (Reference 53).

Variety	Days After Harvest	Modulus of Elasticity	
		kPa	psi
McIntosh	0	4675	678
	10	4480	650
Red Delicious	0	8870	1287
	5	8360	1212
Golden Delicious	0	6720	975
	10	5690	825
Rome Beauty	0	7930	1150
	5	7240	1050

TABLE 7.1.18 Modulus of Elasticity of Corn and Wheat (Ref 76).

Grain	Moisture Content (% w.b.)	Modulus of Elasticity	
		kPa	psi
Corn (Maize, yellow deut)	15.4	404	58,600
	17.0	364	52,800
	18.8	295	42,800
	23.0	219	31,740
Wheat	15.7	317	46,040
	17.0	456	66,190
	17.9	370	53,600
	18.4	302	43,840
	20.7	296	42,960
	21.0	255	36,960
	24.2	132	19,210
	24.8	239	34,700

TABLE 7.1.19 Thermal Conductivities of Some Grains and Non-Agricultural Products.

Product	Moisture Content (% w.b.)	Temperature		Thermal Conductivities, k		(Ref)
		°C	°F	W / (m·°C)	BTU / (hr ·ft·°F)	
GRAINS AND SEEDS						
Corn	13.2	27 - 31	80 - 88	0.177	0.102	(34)
Grain Sorghum	13.0		-	1.57	0.910	(50)
RS 610	16.0		-	1.61	0.932	(50)
	19.0		-	1.71	0.989	(50)
	22.0		-	1.81	1.043	(50)
Oats	8.7		-	0.064	0.037	(34)
	24.2		-	0.103	0.0594	(34)
	12.5		-	0.130	0.075	(34)
Wheat	12.5	30.6	87.0	1.54	0.89	(3)
	12.5	36.2	97.2	1.64	0.95	(3)
	14.0	25.4	77.7	1.64	0.95	(3)
	14.0	32.9	91.2	1.70	0.98	(3)
	23.0	26.3	79.4	1.80	1.04	(3)
	23.0	32.0	89.6	1.85	1.07	(3)
	23.0	32.6	90.7	1.92	1.11	(3)
MISCELLANEOUS						
Sand-dry		360 - 600	680 - 1112	4.85	2.8	(41)
Coke		360 - 600	680 - 1112	2.28	1.32	(41)
		0	32	0.183	0.106	(64)

TABLE 7.1.20 Thermal Diffusivity (α) of Yellow Dent Corn and Soft White Wheat at Various Moisture Contents (Reference 34).

Product	Moisture Content (w.b.)	Temperature		Thermal Diffusitivity, a	
		°C	°F	m^2 / h	ft^2 / h
Corn - yellow dent	0.91	8.7-23.3	47.7-74.0	0.00037	0.00395
	5.08	8.7-23.3	47.7-74.0	0.00035	0.00381
	9.81	8.7-23.3	47.7-74.0	0.00034	0.00364
	14.7	8.7-23.3	47.7-74.0	0.00033	0.00351
	20.1	8.7-23.3	47.7-74.0	0.00031	0.00336
	24.7	8.7-23.3	47.7-74.0	0.00032	0.00344
	30.2	8.7-23.3	47.7-74.0	0.00033	0.00358
Wheat - soft white	0.68	9.1-23.2	48.3-73.8	0.00033	0.00359
	5.45	9.1-23.2	48.3-73.8	0.00032	0.00347
	10.3	9.1-23.2	48.3-73.8	0.00031	0.00331
	14.4	9.1-23.2	48.3-73.8	0.00030	0.00318
	20.3	9.1-23.2	48.3-73.8	0.00029	0.00310
	9.2	26.1-48.9	79-120	0.00041	0.00446
	1.4	26.1-48.9	79-120	0.00041	0.00446
	7.4	26.1-48.9	79-120	0.00038	0.00407

TABLE 7.1.21 The Work and the Force to Initiate Fracture in Single Grains Through Gradual Loading (Reference 6).

Grain	Moisture Content (w.b.)	Kernel Position	Work				Force			
			Avg		Min		Avg		Min	
			mJ	in-lb	mJ	in-lb	N	lb	N	lb
Barley	1.0	Crease down	3.95	0.035	2.82	0.025	62.3	14	53.4	12
(Herta)		Crease on side	3.16	0.028	2.82	0.025	31.1	7	26.7	6
	10.0	Crease down	5.08	0.045	4.75	0.042	57.8	13	48.9	11
		Crease on side	4.75	0.042	4.75	0.042	62.3	14	53.9	12
	17.0	Crease down	5.76	0.051	4.75	0.042	53.4	12	48.9	11
		Crease on side	4.63	0.041	3.28	0.029	44.5	10	35.6	8
Corn	1.0	Germ side down	22.6	0.200	18.9	0.167	142	32	125	28
(DeKalb 244)		Kernel on edge	2.6	0.023	1.92	0.017	53.4	12	44.5	10
	8.0	Germ side down	56.0	0.496	37.7	0.334	400	90	320	72
		Kernel on edge	4.86	0.043	3.73	0.033	191	43	125	28
	17.0	Germ side down	68.5	0.606	57.4	0.508	316	71	285	64
		Kernel on edge	4.86	0.043	3.73	0.033	97.9	22	80.1	18
Oats	1.0	Crease down	8.7	0.077	7.12	0.063	40	9	31.1	7
(Rodney)		Crease on side	12.5	0.111	8.25	0.073	35.6	8	22.2	5
	10.0	Crease down	11.9	0.105	9.38	0.083	35.6	8	31.1	7
		Crease on side	17.1	0.151	8.47	0.075	40	9	31.1	7
	16.0	Crease down	13.2	0.117	9.38	0.083	40	9	35.6	8
		Crease on side	16.2	0.143	13.7	0.121	44.5	10	40	9
Soybeans	1.0	Hilum horizontal	3.84	0.034	2.82	0.025	57.8	13	48.9	11
(O.A.C. 44)		Hilum vertical	3.28	0.029	2.37	0.021	53.4	12	31.1	7
	6.0	Hilum horizontal	4.29	0.038	3.73	0.033	57.8	13	48.9	11
		Hilum vertical	5.31	0.047	4.75	0.042	53.4	12	48.9	11
	10.0	Hilum horizontal	9.38	0.083	5.65	0.050	53.9	12	35.6	8
		Hilum vertical	10.1	0.089	7.12	0.063	40	9	31.1	7
	16.0	Hilum horizontal	31.5	0.279	18.8	0.166	44.5	10	40	9
		Hilum vertical	16.9	0.150	9.38	0.083	31.1	7	26.7	6
Wheat	1.0	Crease down	5.2	0.046	2.82	0.025	57.8	13	40	9
(Genesee)		Crease on side	4.52	0.040	3.73	0.033	48.9	11	40	9
		Crease down	11.1	0.098	8.59	0.076	57.8	13	53.9	12
		Crease on side	6.55	0.058	4.75	0.042	53.9	12	40	9
		Crease down	12.1	0.107	10.4	0.092	44.5	10	35.6	8
		Crease on side	12.9	0.114	8.7	0.077	40	9	35.6	8

TABLE 7.1.22 The Compressive Stress for Yielding and Rupturing of Some Agricultural Products.

Product	Compressive Stress Limits							
	At Harvest		(Ref)	25 days Before		2 days Before		(Ref)
Skin Rupture	kPa	psi		kPa	psi	kPa	psi	
Apples - Jonathan	736 - 919	106.7 - 133.3	(27)					
- McIntosh	689 - 874	100.0 - 126.7	(27)					
- Golden Delicious				1179	171	910	132	(52)
- Red Delicious	736 - 919	106.7 - 133.3	(27)					
- Northern Spy	736 - 781	106.7 - 113.3	(27)					
- Rome Beauty	736 - 1011	106.7 - 146.7	(27)					
- Winesap	874 - 1057	126.7 - 153.3	(27)					
Peaches								
Red Haven - on check	101	14.6	(59)					
- on suture	81	11.7	(59)					
Elberta - on check	75	10.85	(59)					
- on suture	48	6.94	(59)					
Pears - Bartlett	1520 - 2060	220.5 - 298.8	(27)					
- Winter Nelis	1253	181.8	(27)					
Potatoes	3946	572.39						
Yield point								
Golden Delicious				920	119	586	85	(52)

TABLE 7.1.23 The Abrasion Resistance, and Strain Energy of Some Agricultural Products.

Product	Abrasion Resistance			Strain Energy		
	mJ	in-lb	(Ref)	mJ / mm^2	in-lb / in^2	(Ref)
Apples (Golden Delicious)				(2 days before harvest)		
- yield point				0.261	1.49	(52)
- skin rupture					3.9	(52)
Potatoes	1335	11.82	(72)			

TABLE 7.1.24 The Angles of Repose and Internal Friction and the K-ratio of Various Grains, Seeds and Non-agricultural Materials.

Product or Material	Angle of Repose θ	(Ref)	Angle of Internal Friction φ	(Ref)	K-ratio	(Ref)
Alfalfa						
Barley	16°-28°	(3)	38°	(57)	0.42	(56)
Lima beans - dry						
- unshelled						
Snap beans						
Bluegrass						
Bromegrass						
Buckwheat						
Clover						
Corn-shelled	16°-27°	(3)			0.65	(37)
Fescue						
Flaxseed	25°	(3)			0.50	(62)
Grain sorghum	33°	(62)				
Millet						
Oats	32°	(3)			0.42	(56)
Potatoes						
Rapeseed						
Rice, rough	36°	(3)			0.48	(62)
Rice, smooth						
Rye	26°	(3)			0.40	(37)
Sorgo						
Soybeans	29°	(10)				
Sunflower seeds						
Tares	29°	(56)				
Timothy						
Vetch	25°	(62)				
Walnuts						
Wheat	25°-28°		32°	(57)	0.3 - 0.5	(37)
Sudan grass						
Peas						
Hay wafers	45°	(19)				
Clay	45°	(37)	10.2° - 45°	(48)	0.20 - 0.40	(37)
Silt						
Sand - dry, fine	25° - 35°	(37)	25.2° - 35°	(48)	0.35	(37)
- wet, fine	30° - 45°	(37)	15.1° - 30.1°	(48)		
- dry, coarse	25° - 35°	(37)			0.60 - 0.70	(37)
- wet, coarse	30° - 45°	(37)				
Gravel, 6 mm ($^1/_4$ in)	30° - 40°	(37)	30.1° - 40.0°	(48)	0.50	
Earth	30° - 45°	(37)			0.15 - 0.25	(37)
Peat						
Coal - anthracite	27°	(62)	30.1°	(48)	0.30 - 0.40	(37)
- bituminous	27°	(37)	35.0°	(48)	0.30 - 0.40	(37)
Coke	35°	(37)	30.1° - 45.0°	(48)		
Mud	15°-30°	(37)	1.0°	(48)		

7.1.5 Figures of Mechanical Properties.

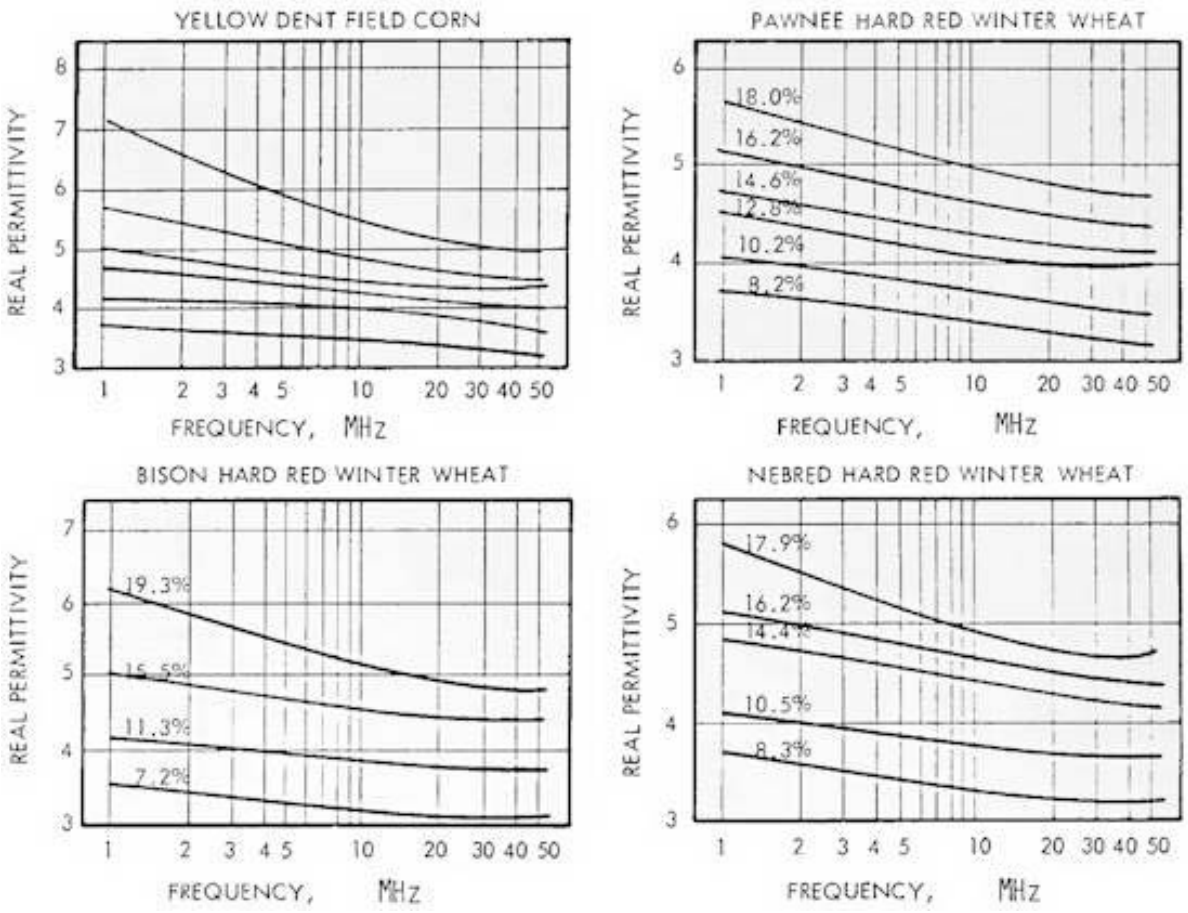

Figure 7.1.1 The real permittivity or dielectric constants of dent corn and winter wheat (Ref. 54).

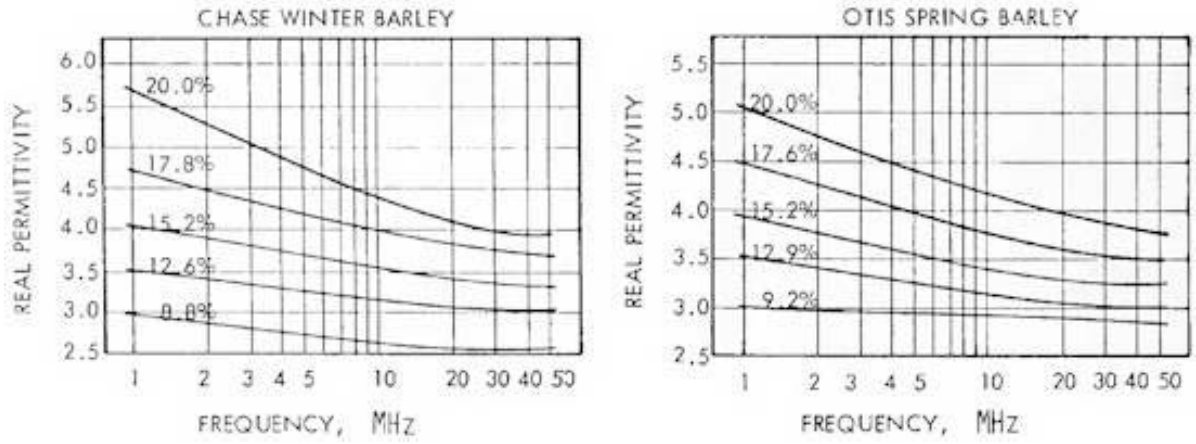

Figure 7.1.2 Real permittivity of chase and otis barley (Ref. 54).

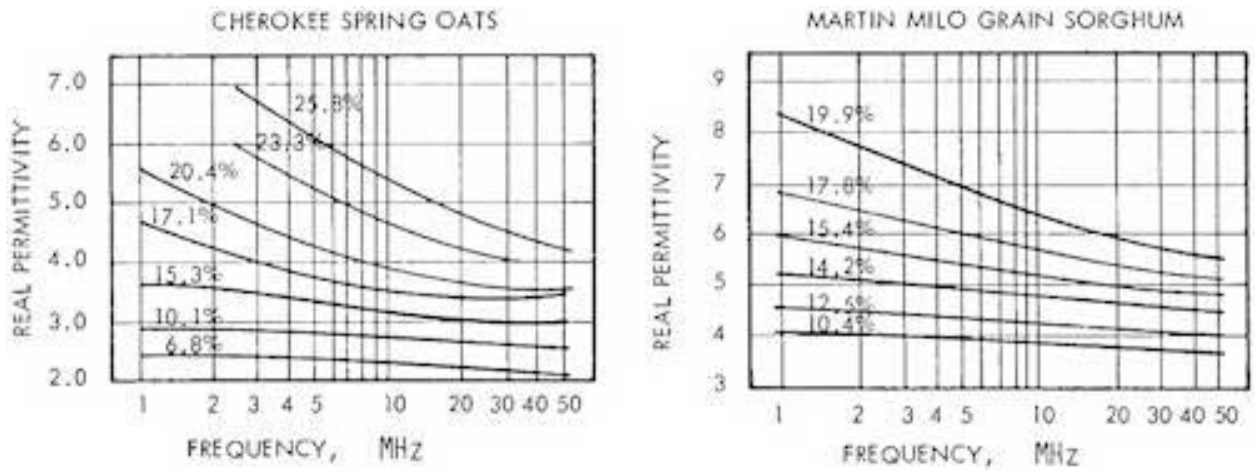

Figure 7.1.3 Real permittivity of oats and grain sorghum (Ref. 54).

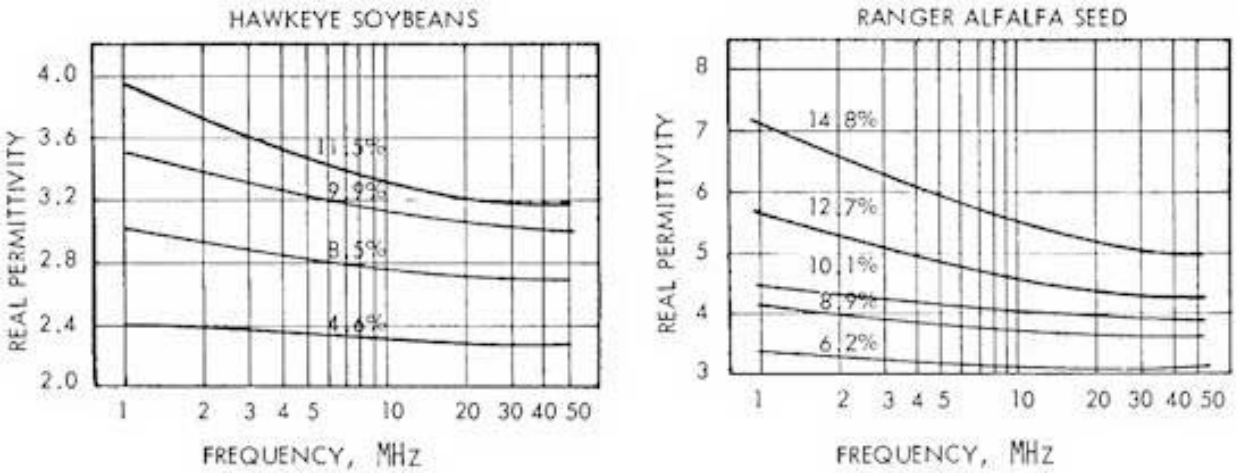

Figure 7.1.4 Real permittivity of soybeans and alfalfa seed (Ref. 54).

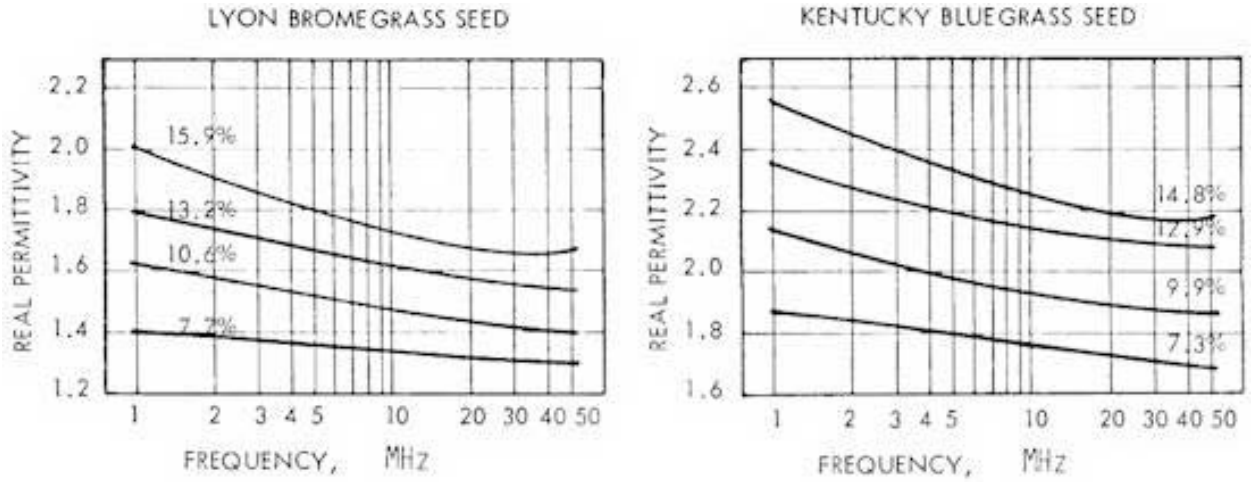

Figure 7.1.5 Real permittivity of bromegrass and bluegrass seeds (Ref. 54).

7.1.6 Tables of Storage Properties.

TABLE 7.1.25 Basic Storage Characteristics of Horticultural Products. [1]

Product	Moisture Content		Storage Temperature								Storage Humidity			Storage Life	
			Recommended			Minimum			Maximum						
	(% w.b.)	(Ref)	°C	°F	(Ref)	°C	°F	(Ref)	°C	°F	(Ref)	Recommended	(Ref)		(Ref)
FRUIT															
Apples- Jonathan	84.0	(62)	1-2	34-36	(62)	-1	30	(4)	7	45	(4)	85-95	(62)	2-4 mo.	(62)
- McIntosh	84.0	(62)	2-3	36-3B	(62)	-1	30	(4)	7	45	(4)	85-90		2-5 mo.	(62)
- G Delicious	84.0	(62)	-1-0	30-32	(62)	-1	30	(4)	7	45	(4)	85-90	(62)	3-6 mo.	(62)
- R Delicious	84.0	(62)	-1-0	30-32	(62)	-1	30	(4)	7	45	(4)	85-90	(62)	3-6 mo.	(62)
- Northern Spy	84.0	(62)	-1-0	30-32	(62)	-1	30	(4)	7	45	(4)	85-90	(62)	4-6 mo.	(62)
- Rome Beauty	84.0	(62)	-1-0	30-32	(62)	-1	30	(4)	7	45	(4)	85-90	(62)	4-7 mo.	(62)
- Winesap	84.0	(62)	-1-0	30-32	(62)	-1	30	(4)	7	45	(4)	85-90	(62)	5-8 mo.	(62)
Apricots	85.0	(62)	0	31-32	(62)	0	31					85-90	(62)	1-2 wk.	(62)
Blackberries	85.3	(14)	0	31-32	(74)	0	32	(4)	4	40	(4)	85-90	(74)	Few days	(74)
Cranberries	87.0	(62)	2-4	36-40	(62)	2	36	(4)	4	40	(4)	80-85	(62)	1-3 mo.	(62)
Gooseberries	88.3	(14)	0	32	(62)	0	32	(4)	4	40	(4)	80-85	(62)	3-4 wk.	(62)
Mullberries			0-4	32-40	(74)							65-75	(74)	8-12 mo.	(74)
Raspberries - red	82.0	(14)	0	31-32	(74)	0	32	(4)	4	40	(4)	85-90	(74)	Few days	(74)
- black	80.7	(14)	0	31-32	(74)	0	32	(4)	4	40	(4)	85-90	(74)	Few days	(74)
Strawberries	90 0	(62)	0	31-32	(62)	0	32	(4)	4	40	(4)	85-90	(62)	7-10 days	(62)
Cherries - sweet	80.0	(62)	0	31-32	(62)	0	32	(4)	7	45	(4)	85-90	(62)	10-14 days	(62)
- sour	84.0	(62)	0	32	(62)	0	32	(4)	7	45	(4)	85-90	(62)	Few days	(62)
Grapes - Vinifera	82.0	(62)	-1-0	30-32	(62)	0	32	(4)	7	45	(4)	85-90	(62)	3-6 mo.	(62)
- American	82.0	(62)	0	31-32	(62)	0	32	(4)	7	45	(4)	85-90	(62)	3-4 wk.	(62)
Peaches	87.0	(62)	0	31-32	(62)	0	32	(4)	4	40	(4)	85-90	(62)	2 wk.	(62)
Pears	83.0	(62)	-1-0	30-31	(62)	-1	30	(4)	0	31		85-90	(62)	2-6 mo.	(62)
Pears - Bartlett	84.0	(62)	-1-0	30-31	(62)	-1	30	(4)	0	31		85-90	(62)	2-3 mo.	(62)
Plums	86.0	(62)	0	31-32	(62)	0	32	(4)	1	33		85-90	(62)	3-4 wk.	(62)
VEGETABLES															
Asparagus	93.0	(62)	0	32	(62)	0	32	(4)	4	40	(4)	95	(62)	3 wk.	(62)
Beans - green, snap	89.0	(62)	7-10	45-50	(62)	7	45	(4)	10	50	(4)	85-90	(62)	8-10 days	(62)
- Lima	67.0	(62)	0- 4	32-40	(62)	0	32	(4)	7	45	(4)	85-90	(62)	2 wk.	(62)
Beets - red-topped	90.0	(14)	0	32	(62)							90-95	(62)	1-3 mo.	(62)
- red-bunched	46.4	(14)	0	32	(62)							90-95	(62)	10-14 days	(62)
Broccoli	90.0	(62)	0	32	(62)	0	32		7	45		90-95	(62)	7-10 days	(62)
Brussel sprouts	85.0	(62)	0	32	(62)							90-95	(62)	3-4 wk.	(62)
Cabbage - early	92.0	(14)	0	32	(62)	0	32	(4)	7	45	(4)	90-95	(62)	3-4 wk.	(62)
- late		(14)	0	32	(62)	0	32	(4)	7	45	(4)	90-95	(62)	3-4 mo.	(62)
Carrots - topped	88.0	(62)	0	32	(62)	0	32	(4)	7	45	(4)	95	(62)	4-5 mo.	(62)
- bunched	64.4	(14)	0	32	(62)	0	32	(4)	7	45	(4)	95	(62)	10-14 days	(62)
Cauliflower	92.0	(62)	0	32	(62)	0	32	(4)	4	40	(4)	90-95	(62)	2-3 wk.	(62)
Celery	94.0	(62)	0	31-32	(62)	0	32		1	33		95+	(62)	2-3 mo.	(62)
Corn	75.5	(38)	0	32		0	32					90-95		8 days	
Cucumbers	96.0	(62)	7-10	45-50	(62)	7	45	(4)	10	50	(4)	95	(62)	10-14 days	(62)
Eggplant	93 0	(62)	7-10	45-50	(62)	7	45	(74)	10	50		85-90	(62)	10 days	(62)
Garlic	74 0	(62)	0	32	(62)							70-75		6-8 mo.	(62)
Lettuce	95.0	(62)	0	32	(62)	0	32	(4)	7	45	(4)	95	(62)	2-3 wk.	(62)
Melons - watermelon	92.0	(62)	2- 4	36-40	162)	2	36	(74)	4	40		B6-90	(62)	2-3 wk.	(62)
- cantaloupe	93.0	(62)	0- 7	32-45	(62)							85-90	(62)	2-3 wk.	(62)
- Honeydew	91.0	(62)	7-10	45-50	(62)	0	32	(4)	7	45	(4)	85-90	(62)	2-3 wk.	(62)
Onions	87.5	(62)	0	32	(62)	0	32	(4)	7	45	(4)	50-70	(62)	6-8 mo.	(62)
Onions - green, bunched	88.2	(61)	0	32	(61)	0	32	(4)	7	45	(4)	70-75	(61)	5-7 mo.	(62)
Parsnips	79.0	(62)	0	32	(62)	0	32	(4)	7	45	(4)	95	(62)	2-4 mo.	(62)
Peas	74.0	(62)	0	32	(62)	0	32	(4)	7	45	(4)	95	(62)	1-2 wk.	(62)
Peanuts - shelled			0	32	(74)							65-75	(62)	8-12 mo.	(74)
- unshelled			0	32	(74)							65-75	(62)	8-12 mo.	(74)
Peppers	92.0		7-10	45-50	(62)							85-90	(62)	8-10 days	(62)
Potatoes	78.0	(62)	4	40	(9)	0	32	(9)	10	50	(9)	85-90	(62)	4-9 mo.	(62)
Potatoes - sweet	69.0	(62)	13-16	55-60	(62)	13	55	(74)				85-90	(62)	4-6 mo.	(62)
Pumpkins	90.0	(62)	7-10	44-50	(62)							70-75	(62)	2-3 mo.	(62)
Rutabaga	89.0	(62)	0	32	(62)							90-95	(62)	6 mo.	(62)

Spinach	93 0	(62)	0	32	(62)	0	32	(4)	1	33	(4)	90-95	(62)	10-14 days	(62)
Squash - summer	95.0	(62)	7-10	55-50	(62)							70-75	(62)	4-6 mo.	(62)
- winter	90.5	(62)	7-10	44-50	(62)	7	44	(74)				85-90	(62)	3-5 days	(62)
Tomato - ripe	94.0	(62)	10	50	(62)	10	50	(4)				85-90	(62)	2-6 wk.	(62)
- mature green	95.0	(62)	13-16	55-60	(62)	13	55	(74)				85-90	(62)	6 mo.	(62)
Turnips	91.0	(62)	0	32	(62)	0	32		2	35		90-95	(74)	10-14 days	(74)
Radish - spring			0	32	(74)							90-95	(74)	2-4 mo.	(74)
- winter			0	32	(74)				18	65	(26)	90-95	(26)		
Sugar beets	83.6	(17)										80			
MISCELLANEOUS															
Malt	7.7	(71)										71-72	(31)	6 mo.	(31)
Oatmeal	8.9	(71)										61-64	(31)	6 mo.	(31)
Rice	9 .7	(71)										67-6B	(31)	6 mo.	(31)

[1] Where applicable, data has *been* adjusted to agree with ref (21)

TABLE 7.1.26 Recommended Moisture Contents of Various Grains, Seeds, Processed Feeds and Miscellaneous Products for Storage.

Product or Material	Moisture Content (% w.b.)	(Ref)	Product or Material	Moisture Content (% w.b.)	(Ref)
GRAINS			**PROCESSED FEEDS**		
Barley	9.6	(71)	Alfalfa meal	8.4	(1)
Lima beans - dry	12.6	(41)	Barley, ground		
- unshelled	66.6	(41)	Barley, malt	6.6	(33)
Snap beans	9.9		Beans (cull)	12.8	(17)
Bluegrass			Beans (screenings)		
Bromegrass			Beet pulp, dried	9.2	(71)
Buckwheat	12.6	(71)	Bone meal, raw	6.7	(71)
Castor beans			steamed	3.1	(71)
Clover			special steamed	2.7	(71)
Corn-shelled	12.9	(71)	Brewer's grains, dried	7.7 - 7.9	(71)
Fescue			Bran (wheat)	9.6	(67)
Flaxseed	5.8	(3)	Corn meal	10.8	(71)
Grain sorghum	9.7	(3)	Fish meal	7.1	(71)
Millet	10.1	(71)	Linseed oil meal (solvent process)	8.5	(71)
Oats	7.7	(71)	Malt (dry ground)	7.7	(71)
Orchard grass			Meat and bone scrap	6.1 - 6.4	(71)
Rapeseed	7.3	(71)	Molasses, beet	25.3	(17)
Rice - rough	9.7	(71)	Molasses, cane or blackstrap	25.8	(17)
- smooth	10.0	(71)	Molasses, corn sugar		
Rye	9.5	(71)	Oat meal	8.9	(71)
Sorgo	12.8	(71)	Oats, ground	10.4	(71)
Soybeans	8.0	(71)	Oats, rolled	10.4	(71)
Sunflower seeds	6.9	(71)	Peas (cull)		
Tares			Peas, screenings	10.8	
Timothy			Poultry-byproducts meal		
Vetch			Rapeseed oil		
Walnuts-black	6.0 - 8.0	(41)	Rice bran	8.8	(71)
Wheat	10.6	(71)	Safflower seed oil meal	8.0	(40)
Sudan grass			Safflower oil feed		
Peas	11.6	(71)	Safflower hulls (ground)	8.7	
Skimmed milk, dried	4.7	(71)	Salt		
Tomato pomacem dried			**MISCELLANEOUS**		
Wheat-germ	11.0	(41)	Coal - anthracite	2.07 - 7.55	
- flour	11.0	(41)	- bituminous	1.18 - 15.41	(41)
- shorts	10.1	(71)	Peat	54.61 - 90.82	(41)
- red dog	11.1	(71)			

TABLE 7.1.27 Grain and Forage Equilibrium Moisture Content (% w.b.) (Ref 26).

	Temperature		Relative Humidity (%)									
Material	°C	°F	10	20	30	40	50	60	70	80	90	100
Barley	25	77	4.4	7.0	8.5	9.7	10.8	12.1	13.5	15.8	19.5	26.8
Lima beans -dry												
- unshelled												
Snap beans												
Bluegrass												
Broomcorn												
Bromegrass												
Buckwheat	25	77	5.0	7.6	9.1	10.2	11.4	12.7	14.2	16.1	19.1	24.5
Castor beans												
Clover												
Corn - shelled	-7	20				10.4	11.8	13.3	15.0	16.6		
- yellow dent	0	32				10.1	11.3	12.6	14.0	15.8		
	10	50				9.2	10.7	12.1	13.6	15.5		
	21	70			7.1	8.3	9.8	11.4	13.2			
	25	77	5.1	7.0	8.4	9.8	11.2	12.9	14.0	15.6	19.6	23.8
	71	160	3.9	6.2	7.6	9.1	10.4	11.9	13.9	15.2	17.9	
- white dent	25	77	5.1	7.2	8.5	9.8	11.2	12.9	13.9	15.5	18.9	24.6
Fescue												
Flaxseed	25	77	3.3	4.9	5.6	6.1	6.8	7.9	9.3	11.4	15.2	21.4
Grain sorghum	4	40	6.8	8.5	9.7	11.0	12.3	13.7	15.3	17.3		
	21	70	6.0	7.7	9.1	10.3	11.5	12.8	14.2	16.0	19.0	
	32	90	5.0	7.0	8.4	9.6	10.8	12.0	13.2	14.7	17.0	
Millet												
Oats	25	77	4.1	6.6	8.1	9.1	10.3	11.8	13.0	14.9	18.5	24.1
Orchard grass												
Rapeseed												
Rice- rough	27	80				9.2	10.4	11.7	13.2	15.0	17.1	
	44	111						10.3	12.3	14.3	16.5	
- polished	25	77			9.2			13.4			18.8	
Rye	25	77	5.2	7.6	8.7	9.9	10.9	12.2	13.5	15.7	20.6	26.7
Sorgo												
Soybeans	25	77		5.5	6.5	7.1	8.0	9.3	11.5	14.8	18.8	
Sunflower seeds [1]					5.2[1]	6.3	6.9	8.1	9.5	11.7	16.9	
Tares												
Timothy												
Vetch												
Walnuts												
Wheat	25	77	5.8	7.6	9.1	10.7	11.6	13.0	14.5	16.8	20.6	
	30	122	4.0	5.8	6.7	8.1	10.0	10.8	12.6	15.1	19.4	
Sudan grass												
Peas			6.6		9.0		11.2		14.1	17.1		

Forages	Relative Humidity %	Equilibrium Moisture	Forages	Relative Humidity %	Equilibrium Moisture
Alfalfa -	1.4	2.3		6.1	7.2
immature @	45.9	21.5	Hay -	20.6	11.1
(27°C)	46.3	23.2	(27°C)	30.1	13.4
(Ref 15)	49.9	26.2	(Ref 15)	35.8	17.4
	64.3	44.9			
	70.8	54.3			
	81.8	74.8			
	84.6	80.6			
Alfalfa -	6.2	4.5	Hay -	6.5	7.6
immature @	8.4	7.5	(10°C)	7.6	8.1
(10°C)	50.0	33.3	(Ref 15)	9.8	8.3
(Ref 15)	56.1	42.0		13.0	9.7
	62.9	47.5		23.8	11.5
	70.2	64.0		32.6	16.6
	71.3	71.2			
	80.3	78.9			

[1] Relative humidities: 31.0, 43.0, 51.0, 62.0, 71.2, 81.1 and 93.0% respectively (Ref 65).

TABLE 7.1.28 The Safe Storage Moisture Contents of Various Seeds and Grains.

	Safe Storage Moisture Content			
Grain	1 year (% w.b.)	(Ref)	5 years	(Ref)
Barley	13	(26)	11	(26)
Clover	10[1]			
Corn - ear	20	(16)	--	
- shelled	13[1]		11	(26)
Fescue	16			
Flaxseed	8			
Grain sorghum	12	(26)	10-11	(26)
Oats	13	(26)	11	(26)
Rice - rough	14	(26)		
Rye	13	(56)		
Soybean	11	(26)	10	(26)
Sunflower	9.5	(65)		
Timothy	16[1]			
Wheat	13-14		11-12	(26)
Peanuts	9.5	(26)		
Hay wafers	14	(46)		
Hay	20	(62)		

[1] For storing bags under farm conditions.

TABLE 7.1.29 The Recommended Storage Humidity And The Maximum Relative Humidity Of The Air Used for Drying Some Grains.

Product	Recommended Storage Humidity At Safe Moisture Content @ 25°C (Ref 70) %	Maximum Relative Humidity Of Air For Drying (Ref 26) %
Barley		60
Corn - ear		60
- shelled	61	60
Grain Sorghum	65	60
Oats	61	60
Rice		60
Rye	71	
Soybeans	68	65
Wheat	64-73	60
Peanuts		75

TABLE 7.1.30 Maximum Air Temperature For Drying Some Grains.

	Drying Temperature					
	Used For Seed		(Ref)	Sold For Commercial Use		(Ref)
	°C	°F		°C	°F	
Barley	41	105	(26)	41	105	(26)
Beans - normal	32	90	(25)	-	-	
- very wet	21	70	(25)	-	-	
Clover - normal	38	100	(25)	-	-	
- very wet	27	80		-	-	
Corn - ear	43	110		54	130	(26)
- shelled	43	110	(26)	54	130	(26)
Fescue - normal	49	120	(25)	-	-	
- very wet	32	90		-	-	
Grain sorghum	43	110		60	140	(26)
Oats	43	110	(26)	60	140	(26)
Rice	43	110	(26)	43	110	(26)
Timothy - normal	38	100	(25)	-	-	
- very wet	27	80		-	-	
Wheat	43	110		60	140	(26)
Peas - normal	38	100	(25)	-	-	
- very wet	27	80		-	-	
Peanuts	32	90		32	90	(26)

TABLE 7.1.31 Recommended Airflow Rates For Drying For Different Grains At Various Moisture Levels Using Unheated Air.

Grain	Moisture Content (%)	Recommended Airflow	
		$L/(s \cdot m^3)$	cfm/bu
Corn - ear	25	100	8
	18	50	4
- shelled	25	60	5
	20	40	3
	18	30	2
	16	10	1
Grain sorghum	25	80	6
	22	60	5
	18	40	3
	15	30	2
Oats	25	40	3
	20	30	2
	18	20	$1^1/_2$
	16	10	1
Peanuts	—	60	5
Rice	—	10-40	1-3
Soybeans	25	80	6
	22	60	5
	18	40	3
	15	30	2
Wheat	25	80	6
	22	60	5
	20	40	3
	18	30	2
	16	10	1

7.1.7 FIGURES OF STORAGE PROPERTIES.

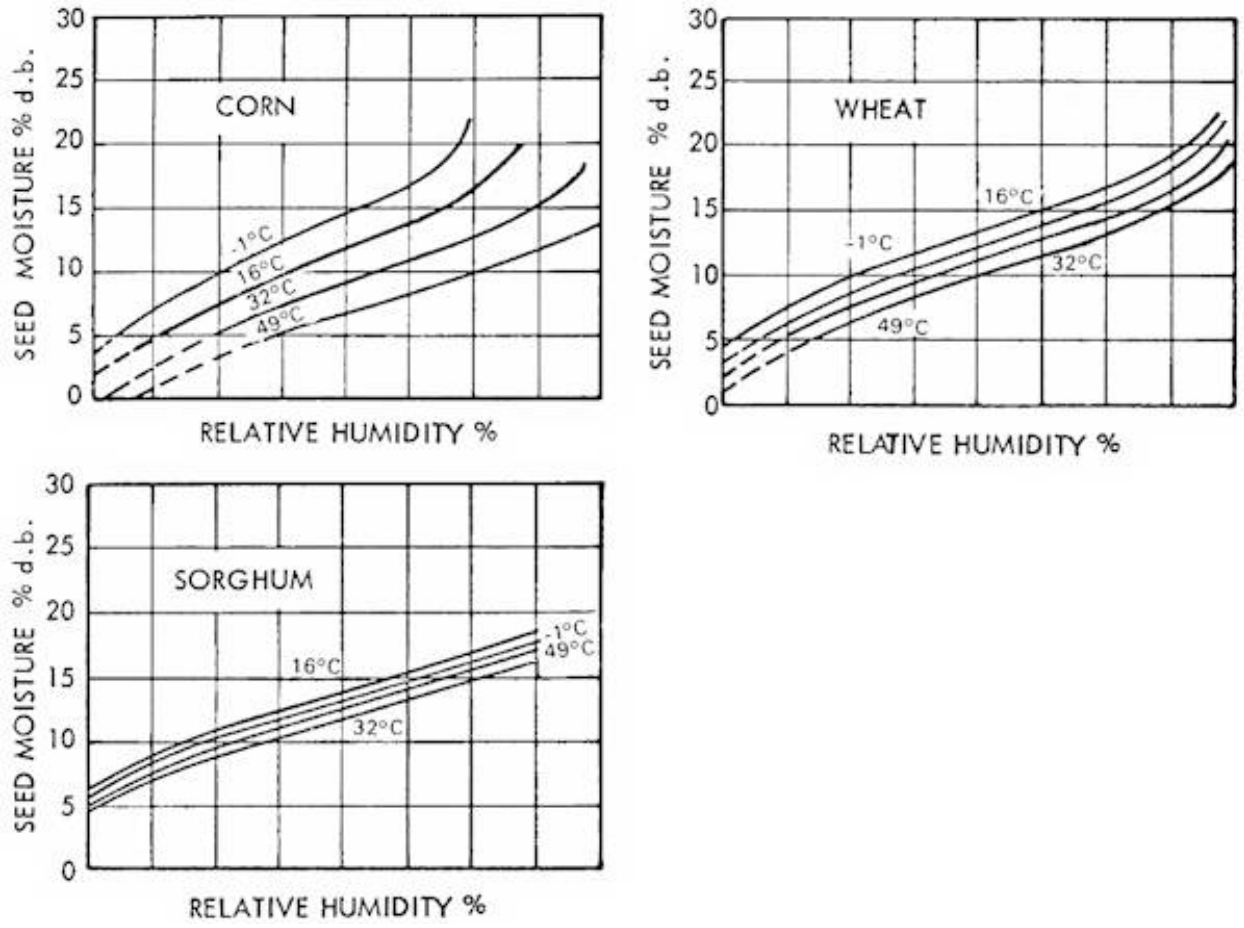

Figure 7.1.6 Hygroscopicity of corn, sorghum and wheat seeds (Ref. 3).

7.1.8 TABLES OF HANDLING CHARACTERISTICS.

TABLE 7.1.32 The Abrasiveness, Flowability And Explosiveness Of Various Grains, Seeds And Processed Feeds (Ref 43).

Grain	Abrasiveness	Explosive Dusting	Flowability
Alfalfa			
Barley	6 non-abrasive	Yes	1 very free-flowing
Lima beans - dry		No	free
- unshelled		No	
Snap beans		No	
Bluegrass			
Bromegrass			
Buckwheat	6 non-abrasive	Yes	1 very free
Castor beans	6 non-abrasive	No	1 very free
Clover	6 non-abrasive	Yes	1 very free
Corn - ear	6 non-abrasive		
- shelled	6 non-abrasive	Yes	1 very free
Fescue			
Flaxseed	6 non-abrasive	Yes	1 very free
Grain sorghum			
Millet			
Oats	6 non-abrasive	Yes	1 very free
Rapeseed		Yes	
Rice - rough	6 non-abrasive	Yes	2 free-flowing
- smooth	6 non-abrasive	No	1 very free
Rye	6 non-abrasive	Yes	1 very free
Sorgo			
Soybeans	7 mildly abrasive	Yes	1 very free
Sunflower seeds			
Timothy	6 non-abrasive	Yes	2 free
Vetch			
Walnuts			
Wheat	6 non-abrasive	Yes	1 very free
Peas	6 non-abrasive	Yes	1 very free
Peanuts - shelled	6 non-abrasive	No	1 very free
Alfalfa meal	7 mildly abrasive	No	3 sluggish
Bone meal	7 mildly abrasive	No	2 free-flowing
Brewer's grains	6 non-abrasive	No	3 sluggish
Corn meal	6 non-abrasive	No	2 free-flowing
Fish meal	6 non-abrasive	No	3 sluggish
Linseed oil meal (solvent process)	6 non-abrasive	No	2 free-flowing
Malt, dry ground	6 non-abrasive	No	2 free-flowing
Oats, rolled	6 non-abrasive	Yes	2 free-flowing
Rice, bran	6 non-abrasive	Yes	2 free-flowing
Salt	6 non-abrasive	No	2 free-flowing
Skimmed milk, dry	6 non-abrasive	No	2 free-flowing
Wheat germ	6 non-abrasive	No	2 free-flowing
Wheat flour Hay wafers	6 non-abrasive	No	3 sluggish, non-free (69)
Bentonite	6 non-abrasive	No	2 free flowing

TABLE 7.1.33 The Contaminability, Aerationability And Tendency To Pack Under Pressure For Various Grains, Seeds And Feeds.

Product or Material	Contaminability	Aerationability	Packing Under Pressure
Alfalfa			
Barley	No	No	No
Lima beans - dry		No	
- unshelled		No	
Snap beans		No	
Bluegrass			
Broom corn			
Bromegrass			
Buckwheat	No	No	No
Castor beans	No	No	No
Clover	No	No	No
Corn - ear		No	
- shelled	No	No	No
Fescue			
Flaxseed	No	No	No
Grain sorghum			
Millet			
Oats	No	No	No
Rapeseed			
Rice - rough	No	No	No
- smooth	No	No	No
Rye	No	No	No
Sorgo			
Soybeans	No	No	No
Sunflower seeds			
Timothy	No	No	No
Vetch			
Walnuts			
Wheat	No	No	No
Peas	No	No	No
Peanuts - shelled	No	No	No
Alfalfa meal	No	No	No
Bone meal	No	No	No
Brewer's grains	No	No	No
Corn meal	No	No	No
Fish meal	No	No	No
Linseed oil meal (solvent process)	No	No	No
Malt, dry ground	No	No	No
Oats, rolled	No	No	No
Rice, bran	No	No	No
Salt	No	No	No
Skimmed milk, dry	Yes	No	No
Wheat germ	No	No	No
Wheat flour	Yes	No	No
Bentonite	No	Yes	No

TABLE 7.1.34 Conveying Velocities For Various Grains.

Grain	Air Velocities							
	Several Single Seeds	(Ref)	Several Small Piles	(Ref.)	Continuous Thin Layer	(Ref)	Bulk Conveying	(Ref)
	(ft/min)		(ft/min)		(ft/min)		(ft/min)	
Castor beans							5000	(20)
Corn	1900 - 2050	(3)	2600 - 2700	(3)	2800 - 3100	(3)	5600	(20)
Oats	1100 - 1350	(3)	1800 - 2200	(3)	2100 - 2300	(3)	4500	(20)
Soybeans	1200 - 1600	(3)	2300 - 2600	(3)	2700 - 300	(3)	-	
Wheat	1600 - 1800	(3)	2200 - 2700	(3)	2000 - 2400	(3)	5800	(20)
	(m/s)		(m/s)		(m/s)		(m/s)	
Castor beans							25.4	
Corn	9.6 - 10.4		13.2 - 13.7		14.2 - 15.7		28.4	
Oats	5.6 - 6.9		9.1 - 11.2		10.7 - 11.7		22.9	
Soybeans	6.1 - 8.1		11.7 - 13.2		13.7 - 15.2		----	
Wheat	8.1 - 9.1		11.2 - 13.7		10.2 - 12.2		29.5	

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