Final Year Project: Semester VIII

'Development of Functional Wheat Bread with Fermented Legume Flour'

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1. ***Executive Summary***

The Project, 'Development of Functional Wheat Bread with Fermented Legume Flour' aims to cover in depth, all the nitty-gritty's involved in setting up a fully operational bread manufacturing plant. The novelty of this project lies in the idea of developing fermented legume bread by combining it with wheat flour, to provide nutritious options for the consumers in this world, which is rapidly shifting towards healthier diet options.

The report is structured in a manner that all the aspects are covered in detail, with relevant figures and calculations attached as required. Overall, the report can be divided into two subparts, the first part catering to the methodology involved in choosing a particular legume and the relevant experimentation done, in order to obtain the required results. Moreover, proper conclusion has been drawn from the same.

The second sub-part of the report throws light upon the Design aspect of the project (Design of Hammer Mill and Dough Mixer), and also the heat and mass profile in the baking oven, which serves as an integral operating unit in the process.

Apart from this, the topics such as 'Process Control Strategy', 'SHE (Safety Health Environment', 'Plant Layout' and Economic Analysis (Including Site Selection) has been explained explicitly, trying to cover all the aspects.

Lastly, relevant conclusions have been drawn from the project completed over the course, with the future scope of this project put forth.

2. Introduction

Wheat is a common constituent of all the foodstuffs and constitutes a major source of diet in most of the developed and developing countries. In a country like India, wheat is a major constituent in the staple diet of the common people. As per statistics, India has a high consumption of wheat flour with an average per person consumption of 200-250 g per day. This accounts to an overall annual consumption of 92 MMT. (FSSAI , 2017)

Daily usage of bread and wheat flour in the daily life was the driving force behind developing a functional wheat bread. Moreover, apart from the conventional wheat flour, legumes are also proving to be an important raw material for production of a wheat bread. Legumes are an important group of plants, which are mainly cultivated for their seeds. These seeds prove to be vital for human nutrition, for they are rich in proteins, minerals, vitamins and sugars. (Tatiana, Frančáková, Líšková, & Tokár, 2012)

The project aims at developing a novel functional wheat bread using a certain proportion of legume flour. Initially, three different types of legumes are being selected and then, correspondingly, an optimum legume is established considering all the aspects. This optimum legume is selected by measuring the increase in the free amino acid content in the legume during fermentation for each legume and then comparing them to select the most suitable legume. Apart from this, the anti-nutritional properties in the legume also play a vital role in determining the optimum legume. Lesser the anti-nutritional content, more suitable is the legume.

Apart from carrying out laboratory tests to establish the choice of legume, other design aspects to set up a plant are considered in greater detail, looking at all the practical aspects, such as the design of a hammer mill required to crush the raw materials to make flour, design of the dough mixer, determination of a temperature profile, moisture loss profile during the process of baking etc. Apart from this major focus is also given on the plant layout, working schedule, economic analysis, safety procedures, site selection etc.

3. Relevance of project

The project finds relevance in day to day life, and especially in a country like India, mainly due to the high consumption of wheat in the daily staple diet. Moreover, a large number of people are affected by protein deficiency, mainly due to the vegetarian diet adopted by the people of India. Considering the economic market, India's bakery and cereal market is worth $1 billion, the 3rd largest in Asia Pacific after Japan and Australia. With a massive number of people eating breads, incorporating various nutrients such as protein essentials for a healthy diet can be beneficial.

India produces more than 90 million tonnes of wheat. Most of it is used for direct consumption in the form of chapati & bakery products. The per capita consumption of bakery products in the country is about 2 kg per annum, against 50-100 kg bread alone in western countries. Consumption of bread is increasingly fast at estimated rate of 135% with a scope for further enhancement. The manufacture of bread in small towns and villages shall not only meet the local demand but generate employment opportunities in the vicinity.

Before developing the bread and experimenting with the type of legumes, a market survey on the existing types of wheat breads available in the market was made, along with its nutritional values and composition (Refer Annexure). The data was then tabulated, which helped us to draw out relevant inferences.

The parameters which were mainly studied were:

- Brand of the product
- Quantity under sale
- Market Price (in INR)
- Ingredients (Composition)
- Proteins (Per 100 gm)
- Carbohydrates (Per 100 gm)
- Energy in kcal (Per 100 gm)

A similar analysis was carried out, even for different types of wheat flour, the data of which was procured from a nearby outlet. (Refer Annexure). This study gives us a perspective about the different types of breads available and their prices which helps us in the economic analysis and drives us to prepare a market relevant product.

4. Legume: Selection & Properties

The aim of the project involved selection of a legume to manufacture the functional wheat bread. The legume selection was based on a number of factors as follows:

4.1. Health benefits

They provide fiber, protein, carbohydrate, B vitamins, iron, copper, magnesium, manganese, zinc, and phosphorous. Legumes are naturally low in fat, are practically free of saturated fat, and because they are plant foods, they are cholesterol free as well. Legumes are an integral part of many healthy eating patterns, including the Mediterranean style of eating, the DASH eating plan, vegetarian and vegan diets, and lower-glycemic-index (GI) diets. (Rani, M., & Amy, 2015) Along with being a highly nutritious food, evidence shows that legumes can play an important role in the prevention and management of a number of health conditions like:

a) *Type 2 Diabetes*: A diet rich in plant-based foods, including legumes, and lower in refined grains, sugar-sweetened beverages, and processed meats has been shown to lower the risk of developing type 2 diabetes and, for those who have diabetes, to improve both glycemic and lipid control.
b) *Hyperlipidemia:* Regularly eating legumes may help lower total and LDL cholesterol levels. A meta-analysis of 10 randomized, controlled trials in which non-soy legumes were consumed for a minimum of 3 weeks revealed that eating legumes has a cholesterol lowering effect. (Bazzano, AM, & MT, 2011)
c) *Hypertension*: Legumes are rich in potassium, magnesium, and fiber, all nutrients that have a positive impact on blood pressure management.
d) *Weight Management:* A diet that regularly includes legumes may help with weight control. The fiber, protein, and slowly digested carbohydrate found in legumes may aid in satiety. Using data from the National Health and Nutrition Examination Survey (NHANES), it was observed that adults who consumed a variety of legumes had significantly lower body weights compared with those who did not consume legumes.

4.2. Anti-nutritional Factor

Certain anti-nutritional factors in case of foodstuffs were found out to be as follows:

Table 1: Different types of anti-nutrients present

Number	Antinutrient	Heat Sensitive
1	Trypsin inhibitors	Yes
2	Hemagglutinin	Yes
3	Glucosinolates	No
4	Cyanogen	No
5	Phytic acid	Yes/No
6	Saponins	No
7	Tannins	No
8	Phytoestrogens	No
9	Gossypol	No
10	Antivitamins	Yes
11	Amylase inhibitor	Yes
12	Invertase inhibitor	Yes
13	Arginase inhibitor	Yes
14	Cholinesterase inhibitor	?
15	Dihydroxyphenylalanine	No
16	Mimosine	No
17	Cyclopropenoic acids	No

Table 2: Anti-nutrients present in certain foodstuffs

Foodstuff	Compounds
Corn	1,5,8,12
Wheat	1,2,5,8,11,15
Rice	1,2,4,5,7,11
Barley	1,2,5,8
Sorghum	1,2,4,5,7,11
Soybean	1,2,3,5,6,8,10
Cottonseed	5,8,9,11,17
Rapeseed	3,5,7
Peanut	1,2,5,6,8
Sunflower	1,7,13
Sesame	5
Chick Pea	1,4,5,8
Lentil	1,2,5,6
Alfafa	1,5,8,12
Potato	1,2,4,8,11,12,14

As our project is specifically based on the legume flour, we take a look at the antinutritional factors present in different types of legumes as follows:

Table 3: Antinutritional factors in legumes

Antinutritional factors in legumes

Antinutritional factor	Action in human body	Source	Methods to overcome
Type A			
1. Protease inhibitors	Interferes in human digestive process and nutrients utilization	Chickpea, pigeonpea , limabean , kidney bean, peanuts, cowpea, garden pea	By heat treatments, germination, fermentation
2. Lectins or hemaggluttins	Agglutinates red blood cells and other types of cells, toxic to human when exceeds the limits	Lentil, peas, soybean, kidney beans, peanuts	Traditional cooking, germination
3. Saponins	Bitter taste, hemolyze red blood cells	Alfalfa , soybean, french bean, pisum	--
Type B			
1. Phytic acid	Makes mineral insoluble by binding strongly with them particularly with Ca, Fe, Mg, Zn and other trace elements	Soybean , fababean, lentil, chickpea and phaseolus beans	Germination, applying phytase enzyme
2. Gossypols	Binds with Fe and amino acids	Cotton seed meal	CaOH addition reduces gossypol
3.Glucosinolates	Causes legume goitre in childrens, due to iodine deficiency	Brasica, soybean, peanuts	

Anti-nutrients are plant compounds that reduce the body's ability to absorb essential nutrients. They are not a major concern for most people, but may become a problem during periods of malnutrition, or among people who base their diets almost solely on grains and legumes. The broad classification of the anti-nutrients has been mentioned in the table above.

The most commonly found anti-nutrient is ‘Phytic Acid’. Myoinositol 1,2,3,4,5,6-hexakisdihydrogen phosphate is found in cereals and legumes at levels ranging from 0.4% to 6.4%, by weight. PA is the primary phosphate reserve in most seeds accounting for 60% to 90% of total phosphorus. In monocotyledons such as wheat and rice, PA is present in the germ of corn Sesame, dicotyledonous seeds such as legumes, nuts, and oilseeds, PA is found closely associated with proteins and is often isolated or concentrated with protein fraction of these foods. (Khokhar & Apenten)

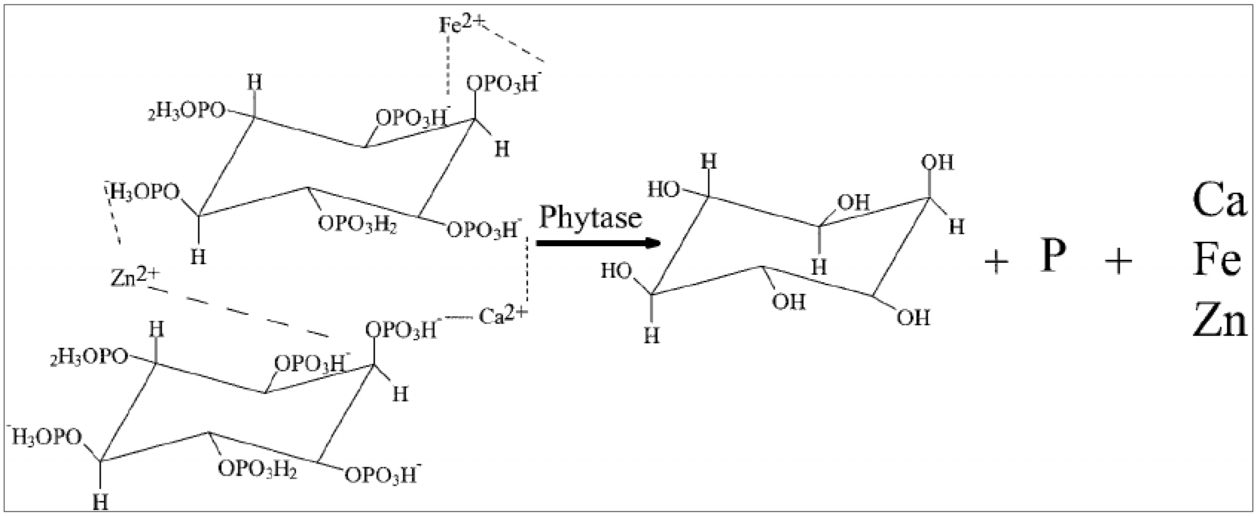


Figure 1: Chemical Structure of Phytic Acid (Myoinositol 1,2,3,4,5,6-hexakisdihydrogen phosphate)

The legumes chosen for this project had Phytic acid as its principal antinutritional factor. The steps to evaluate the Phytic Acid concentration have been explained.

Out of all the available legumes, four legumes were chosen, based on a number of factors such as: easy availability in market, market demand, and utility in daily life, innovation, protein content and nutritional properties.

The four legumes chosen were as follows:

- White peas
- Adzuki Beans
- Black Lentils
- Soyabean

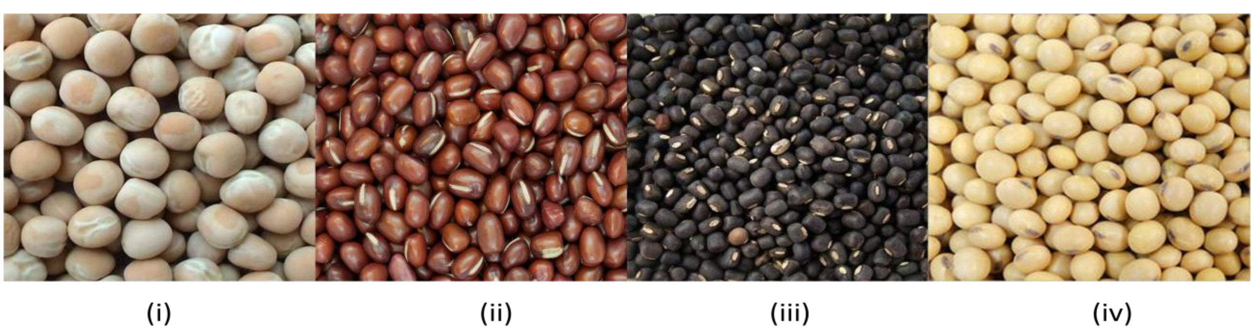


Figure 2: Different types of legumes chosen: i- White peas, ii- Adzuki Beans, iii- Black lentils, iv- Soybean

Health benefits of the legumes observed in this study are as follows,

1. **White beans** are loaded with even more cancer-fighting dietary fiber than healthy red beans. By eating these fiber-rich superfoods, one can reduce the risk of many cancers and other potential killers, including brain aneurysms. These white beans are also loaded with flavonoids and other phytochemicals that slow cancer cell growth and decrease chronic inflammation. (Oz, 2012)
2. **Adzuki beans** are full of protein, fibre and folic acid and are considered as vital part of diet in pregnant and lactating mothers.These nutritious beans are primarily red in color, but white, black, and mottled cultivars can also be found in certain areas. The high content of B vitamins, particularly folic acid, can prevent the development of birth defects in unborn babies. Neural tube defects are a direct result of a folate deficiency, so the high content in adzuki beans can ensure a healthy delivery. (Kumari, 2017)
3. **Black Lentils** are rich in complex carbohydrates, a nutrient that boosts the metabolism and helps the body to burn fat. They are an excellent source of fiber, which can help reduce cholesterol levels. Lentils are also an outstanding source of folate and magnesium. The health benefits of eating lentils are numerous. Because they are high in protein and low in fat, lentils make an excellent substitute for meat, and they can help improve heart health. Beans also contain something that meat lacksóphytochemicals. Phytochemicals help block the action of cell-damaging free radicals, which can cause everything from cancer to neurodegenerative diseases like Parkinson’s. (Rolland, 2019)
4. The health benefits of **Soybean** are such that it helps in improving metabolic activity, helps in healthy weight gain, prevents cancer, boosts heart health, relieves menopausal symptoms, boosts digestive health, improves bone health, prevents birth defects, improves blood circulation, controls diabetes, relieves sleep disorders, helps in cell growth and regeneration. (Benefits of Soybean And Its Side Effects)

5. Experimental Procedure

Two major tests were conducted to assess the efficacy of the three legumes considered (Adzuki beans, White peas and Black Lentils). The detailed procedure for the two tests conducted is attached as annexure.

For the experiment, each of the three legumes was subjected to fermentation for a period of 120 hours, with sample being analyzed for every 12 hours. Moreover, in each of these cases, the yeast concentration was varied from 1% to 2%, with increments of 0.5%. In all, the totals of 90 samples were analyzed individually, for both the Phytic acid determination and the Free Amino Acid content.

Firstly, the Phytic acid test, which is a long procedure, is used to determine the amount of Phytate present in the sample. The analysis of absorbance of each of these samples was instrumental in giving out fair conclusions about the optimization process required and further formulation. With increasing fermentation time the amount of Phytate present in the sample decreases which can be measured by calculating the decreasing absorbance with time.

Simultaneously, the Cd-Ninhydrin test was carried out for all the 90 samples. Similar to the earlier test, the absorbance was analyzed, which was then used as a measure to determine the behavior of the free amino acid content present in the legume during optimization. The free amino acid content in the sample should increase with the increase in the fermentation time.

Following this, plots of absorbance versus time for each legume was plotted on the same graph to compare the rate of increase of the free amino acid with time and the rate of decrease of the anti-nutritional properties with time.

6. Results and Discussion

6.1. Phytic Acid Test

Phytic acid was measured as ferric phytate following the method proposed by Wheeler & Ferrel (1971). In this method, phytate is extracted with trichloroacetic acid (TCA) and precipitated as ferric salt. The iron content of the precipitate is determined spectrophotometrically and the phytic acid content is thus estimated from the absorbance. A known amount of the sample was extracted in 3% TCA for 45 min. Ferric sulphate solution was added to the extract and the contents were transferred to a boiling water bath for 45 min. The solution was then filtered, and the precipitate was washed in TCA, 1.5N NaOH and distilled water. The precipitate was then dissolved in concentrated HNO3 and made upto a known dilution in a volumetric flask. KSCN was added to the aliquot in the ratio of 1:1 by volume just before measuring the absorbance as this reagent is unstable. The absorbance was measured at 480 nm using a spectrophotometer. A standard curve was developed using phytic acid. For the analysis of Phytic acid content in the legumes, the sample was analyzed for 3 different yeast concentrations, ie. 1%, 1.5% and 2%. The fermentation was continued for 120 hours and the absorbance was reported.

6.1.1. Observations

For Black Lentils,

Table 4: Table of phytic acid content with increasing time and changing yeast content for black lentils

Time (hr)	Phytic acid (mg/g)for 1% yeast	Phytic acid (mg/g)for 1.5% yeast	Phytic acid (mg/g)for 2% yeast
0	8.95	8.95	8.95
12	5.61	6.11	6.13
24	4.72	4.87	4.88
36	2.83	3.09	3.96
48	0.74	0.96	1.07
60	0.45	0.54	0.61
72	0.36	0.44	0.48
84	0.35	0.42	0.47
96	0.34	0.40	0.45
108	0.33	0.39	0.43
120	0.32	0.38	0.42

For White Peas,

Table 5: Table of phytic acid content with increasing time and changing yeast content for white peas

Time(hr)	Phytic acid (mg/g)for 1% yeast	Phytic acid (mg/g)for 1.5% yeast	Phytic acid (mg/g)for 2% yeast
0	8.66	8.66	8.66
12	7.84	7.93	7.86
24	5.48	5.62	5.32
36	4.24	4.31	4.15
48	1.80	1.83	1.66
60	1.53	1.46	1.27
72	1.19	1.11	0.85
84	1.15	1.02	0.67
96	1.10	0.97	0.59
108	1.07	0.89	0.52
120	1.03	0.86	0.48

For Adzuki Beans,

Table 6: Table of phytic acid content with increasing time and changing yeast content for adzuki beans

Time(hr)	Phytic acid (mg/g)for 1% yeast	Phytic acid (mg/g)for 1.5% yeast	Phytic acid (mg/g)for 2% yeast
0	12.51	12.51	12.51
12	10.49	10.13	9.97
24	9.03	8.44	7.89
36	7.08	5.32	4.43
48	1.94	1.64	1.24
60	1.01	0.83	0.75
72	0.89	0.78	0.68
84	0.78	0.74	0.64
96	0.70	0.70	0.62
108	0.66	0.68	0.60
120	0.63	0.66	0.59

Curves for Phytic acid content vs Time for the Legumes:

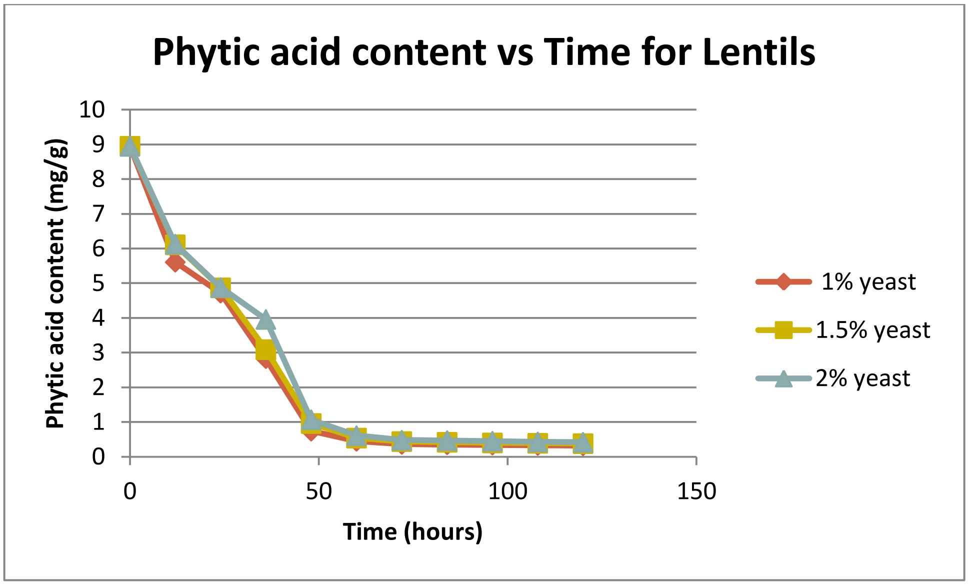


Figure 3: Plot of phytic acid content versus time to indicate the decreasing anti-nutritional properties for lentils

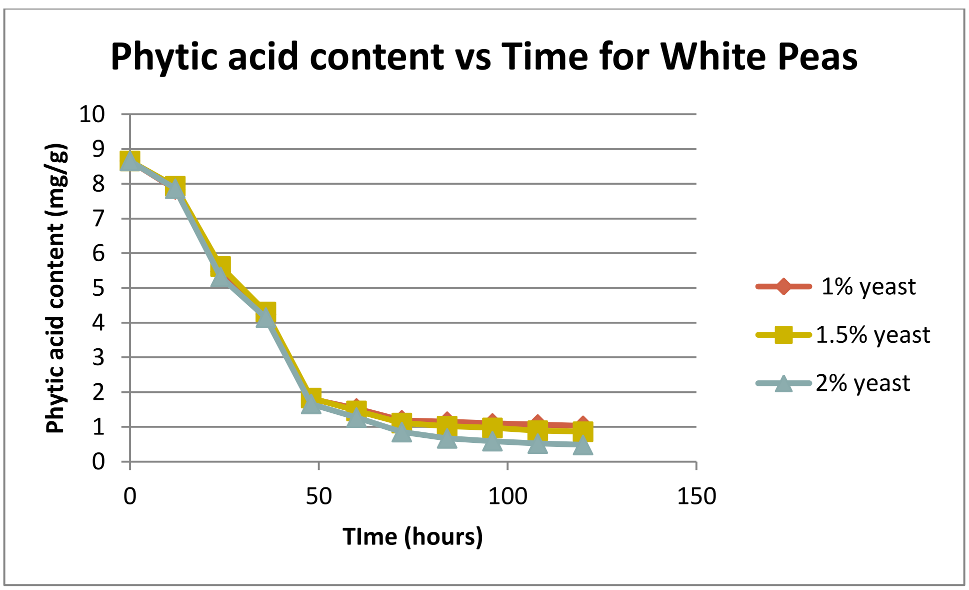


Figure 4: Plot of phytic acid content versus time to indicate the decreasing anti-nutritional properties for white peas

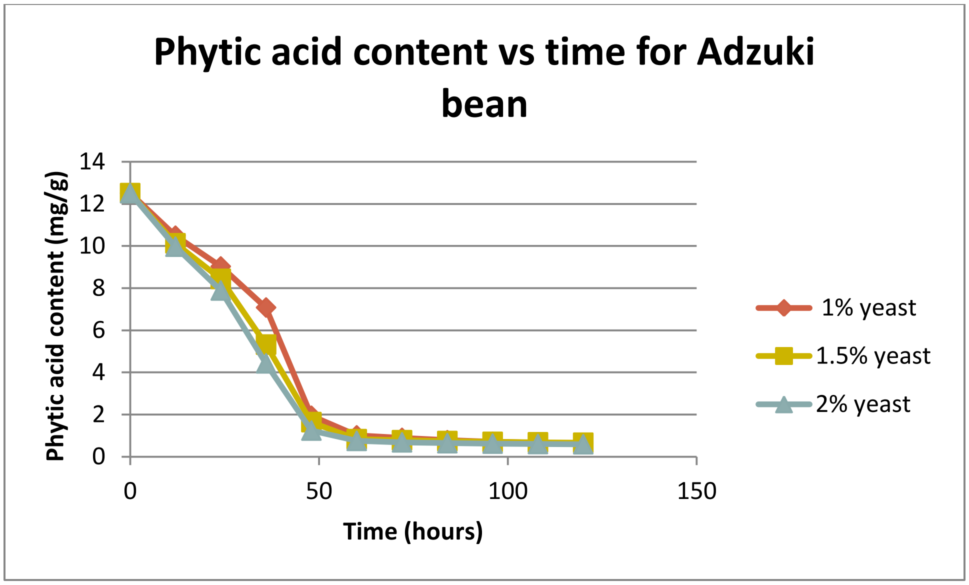


Figure 5: Plot of phytic acid content versus time to indicate the decreasing anti-nutritional properties for adzuki beans

6.2. ***Ninhydrin Test***

6.2.1. ***Observations***

For Black Lentils,

Table 7: Table of free amino acid content with increasing time and changing yeast content for black lentils

Time (hr)	1%	1.5%	2%
0	207.8974	207.8974	207.8974
12	237.5198	283.5198	314.1463
24	267.4924	369.4567	405.1242
36	303.4933	448.3416	464.1826
48	342.1996	513.1654	516.1942
60	385.4628	570.1847	546.0942
72	452.583	620.1987	575.4037
84	525.9426	665.1860	599.1438
96	588.1648	693.492	622.1729
108	628.4967	713.4924	635.1038
120	653.5581	725.7933	642.1053

For White Peas,

Table 8: Table of free amino acid content with increasing time and changing yeast content for white peas

Time(hr)	1%	1.5%	2%
0	222.0316	222.0316	222.0316
12	252.8365	294.4682	330.1473
24	285.4615	379.9437	423.6428
36	320.3648	458.4934	483.5473
48	364.1643	518.4936	536.0529
60	423.0295	578.4627	581.7416
72	491.4316	629.1463	612.2046
84	562.6025	678.1678	638.5319
96	625.7931	717.4384	660.7164
108	670.8962	752.4934	675.3155
120	698.4135	775.1472	685.7864

For Adzuki Beans,

Table 9: Table of free amino acid content with increasing time and changing yeast content for adzuki beans

Time(hr)	1%	1.5%	2%
0	166.3158	166.3158	166.3158
12	191.4926	216.8467	259.4182
24	217.5846	289.6792	342.1827
36	249.6468	347.8172	383.1325
48	283.1654	395.1864	425.1472
60	319.4682	438.1672	445.0315
72	368.1645	477.1834	458.1320
84	424.3165	510.1724	478.1472
96	468.7589	536.4927	496.1423
108	502.7758	560.1728	506.7021
120	522.8464	580.1716	513.6842

Curves for Free Amino Acids versus Time for the Legumes:

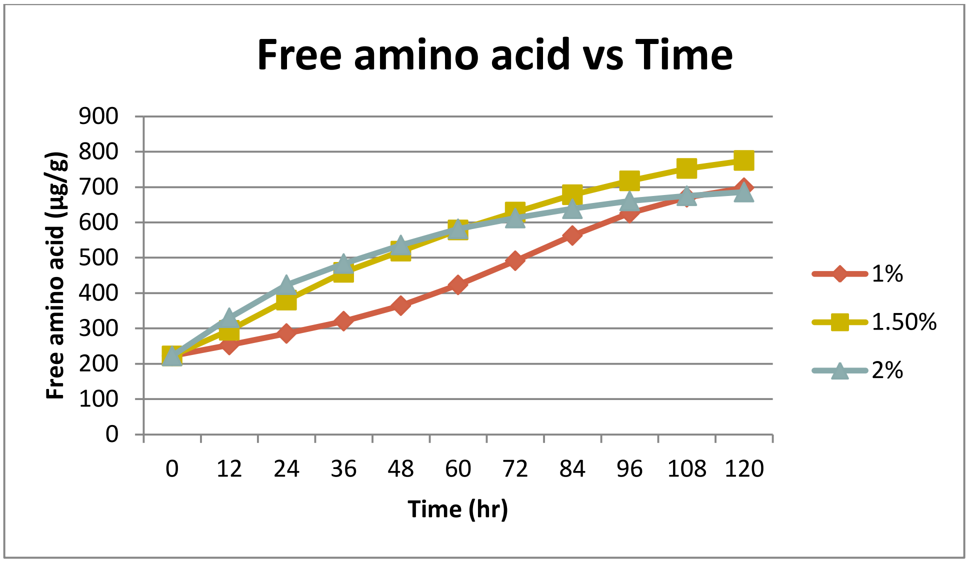


Table 10: FAA content versus Time for White Pea

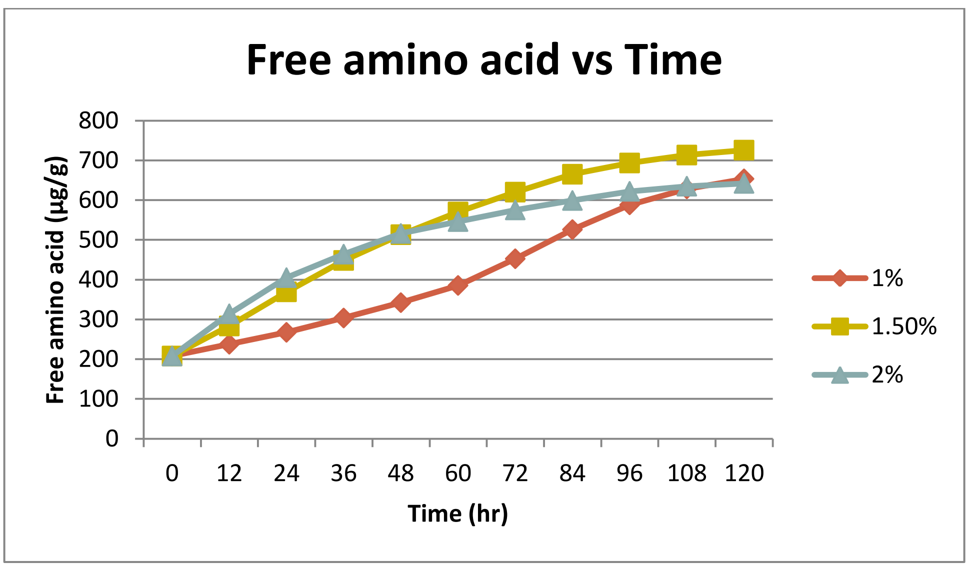


Table 11: FAA content versus Time for Lentils

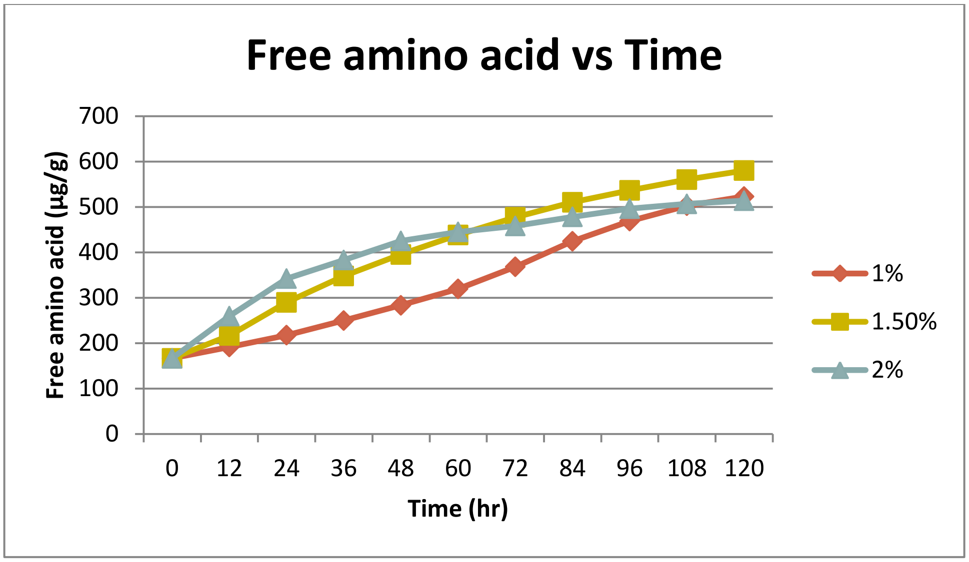


Table 12: FAA content versus time for Adzuki Beans

6.3. ***Conclusions***

For all the three legumes, it is desired that the amount of Phytic acid reduces with time and free amino acid increases with time, thereby implying a reduction in its anti-nutritional properties. From the curves, it can be observed that, for all the three legumes alike, the content decreases with time and the free amino acid content increases with time.

Absorbance is a direct measure to assess the Phytic acid concentration and free amino acid concentration.

6.4. ***Specific Loaf Volume***

Specific Loaf Volume of Bread is the Volume of the bread per unit mass of the bread. Generally, a high specific loaf volume of bread is desirable. Volume was measured by rapeseed displacement after cooling. Specific volume (cm3·g-1) was calculated by dividing the loaf volume by weight.

Standard protocol for measurement of Specific Loaf Volume was followed:

Emulsifier	Legume Flour	SLV (cm^3/g)
1%	20%	1.33
1%	25%	1.66
1%	30%	2

0.7%	20%	1.833
0.7%	25%	1.66
0.7%	30%	2.166
0.3%	20%	2
0.3%	25%	2.166
0.3%	30%	2.33
0.5%	22.5%	1.833
0.85%	22.5%	2
0.7%	27.5%	2

6.5. Measurement of Hardness

Hardness of bread samples was measured using a texture analyzer using a 25-mm diameter cylinder probe P/25R. The bread samples were analyzed after having been cooled for 1 h. The bread was cut into slices from the central regions of the loaf. Samples were compressed. From the graphical representation of the texture profile analysis, the value of the maximum force during the first cycle of compression was recorded as the hardness or firmness. It also helps in assessing new formulations, or how different conditions affect shelf-life.

Sample	Hardness (gF)
S1	3583.5
S2	6726.1
S3	8170
S4	3478
S5	1236.1
S6	6616
S7	1310
S8	3074
S9	8968
S10	4021.6
S11	1899
S12	3465.2

6.6. Hunter Lab Colorimeter

Hunter's Lab color scale is similar to XYZ color scale; the former is more visually uniform than the latter. It consists of three axis: L-axis, a-axis and b-axis. L-axis ranges from -100 (complete black) to +100 (perfect reflecting diffuser). Whereas in a-axis, '+a' indicates redness, '-a' indicates green, and +b indicates yellow, -b indicates blue.

Standard Protocol was followed and the results were:

Sample	Emulsifier	Lentil Flour	L*	a*	b*	ΔE	
	-	-	61.47	-10.59	20.46	-	(Whole wheat flour as standard)
S1	0.3%	20%	51.78	13.8	29.18	27.65514	Crust part of bread
			55.38	2.89	14.43	15.97371	Crumb part of bread
S2	0.3%	25%	54.59	10.89	27.45	23.61324	Crust part of bread
			57.69	3.64	17.48	15.02204	Crumb part of bread
S3	0.3%	30%	34.59	12.65	13.38	36.89225	Crust part of bread
			54.81	3.27	15.91	16.03614	Crumb part of bread
S4	0.7%	20%	51.59	12.74	30.09	27.10425	Crust part of bread
			54.19	2.59	14.9	16.05068	Crumb part of bread
S5	0.7%	25%	48.86	8.88	23.37	23.37865	Crust part of bread
			56.06	3.52	17.63	15.3743	Crumb part of bread
S6	0.7%	30%	37.51	12.53	13.11	34.0975	Crust part of bread
			58.44	3.32	15.1	15.2118	Crumb part of bread
S7	1%	20%	51.48	10.59	26.9	24.28716	Crust part of bread
			33.95	2.43	9.43	32.38104	Crumb part of bread
S8	1%	25%	54.46	9.01	25.29	21.36888	Crust part of bread
			56.89	3.2	16.97	14.94392	Crumb part of bread
S9	1%	30%	38.73	14.9	18.61	34.2092	Crust part of bread
			57.93	2.71	15.43	14.6534	Crumb part of bread
S10	0.5%	22.5%	52.84	11.34	24.02	23.9146	Crust part of bread
			37.66	1.92	11.55	28.3341	Crumb part of bread
S11	0.85%	22.5%	53.25	12.03	21.06	24.0256	Crust part of bread
			53.79	7.32	12.94	20.8878	Crumb part of bread
S12	0.7%	27.5%	42.75	11.94	19.89	29.2979	Crust part of bread
			55.66	3.31	15.74	15.7875	Crumb part of bread

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Figure 6: Fermentation process in baking bread

Figure 7: Three samples of bread with fermented black lentils and varying amounts of emulsifier

5. Sensory Analysis and Fuzzy Logic

Attributes of the bread like aroma, appearance, taste, flavor and texture were determined using the sensory analysis and fuzzy logic approach. A panel of 16 healthy members aged between 18 and 23 was selected for the sensory analysis. They were asked to rate the attributes from 0 to 5, 0 being ‘poor’ to 5 being ‘excellent’. The probability of biasedness between the tastes of two consecutive samples was nullified by rinsing the mouth of each panellist using lukewarm water.

Calculations of overall sensory scores in the form of triplets, converting them in membership functions on a Fuzzy scale and ranking the samples with their quality attributes based on similarity values were performed according to the methods described by Sinija and Mishra (2011).

A fuzzy similarity approach was used for sensory evaluation as it utilizes linguistic data from subjective evaluation along with the accurate precise data available from objective evaluation (Das 2005). The quality attributes identified for bread, with respect to which the samples were scored were aroma, appearance, flavour, mouthfeel and texture. The calculations of the overall sensory scores in the form of triplets, then converting them to triangular membership functions on a fuzzy scale, and ranking the attributes as well as the samples based on their similarity values was performed according to the method described by Chakraborty et al. (2015). A higher value of the similarity index for the same membership function (Fi) represented that the sample was ranked higher by the panellists.

In brief, the sensory score given by the panelists was defuzzified into a triangular distribution pattern named triplet. The triplet of relative weightage (QR) for the quality attributes in general was calculated by taking the ratio of individual triplet to the maximum among the sum of triplet sides. The overall sensory score (SOi) for the *i*th sample was calculated from the equation:

$$SOi = \sum_{j=1}^{5} \begin{matrix} (s_i \; for \; j^{th} \; attribute) \times \\ (QR \; for \; j^{th} \; attribute) \end{matrix}$$

where *j* represents the sensory attributes analyzed like aroma, mouth feel, and aftertaste.

Membership functions (F1-F6) of standard fuzzy scale are represented as:

Not at all necessary (F1)=(1, 0.5, 0, 0, 0, 0, 0, 0, 0, 0)
Somewhat necessary (F2)=(0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0, 0)
Necessary (F3)=(0, 0, 0.5, 1, 1, 0.5, 0, 0, 0, 0)
Important (F4)=(0, 0, 0, 0, 0.5, 1, 1, 0.5, 0, 0)
Highly important (F5)=(1, 0.5, 0, 0, 0, 0, 0.5, 1, 1, 0.5)
Extremely important (F6)=(0, 0, 0, 0, 0, 0, 0, 0, 0.5, 1)

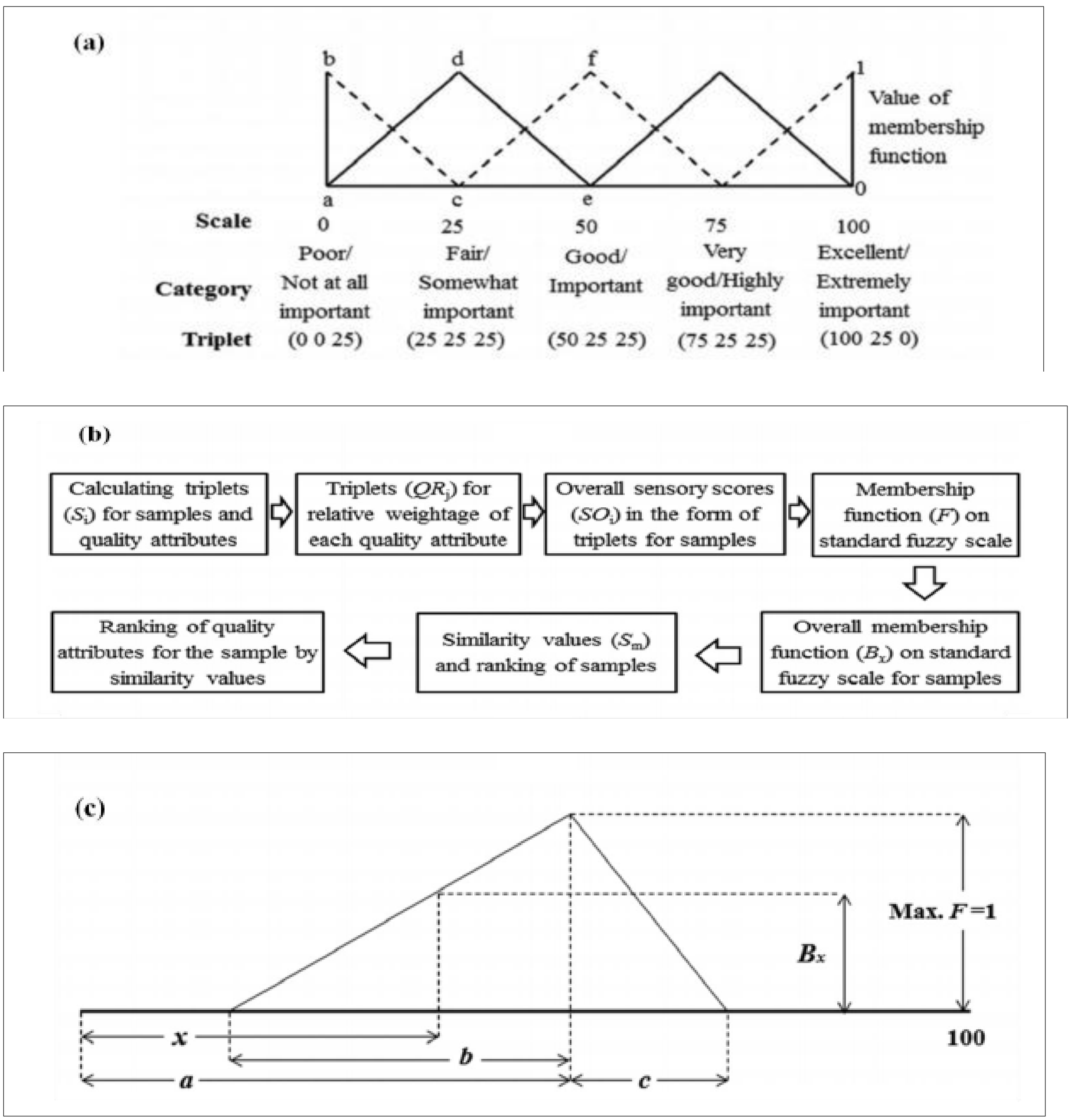


Figure. Overview of sensory evaluation using fuzzy logic (a) 5-point sensory scale and corresponding triplets; (b) major steps involved in fuzzy modeling of sensory data, and (c) representing the triplets (a b c) into the membership function (Chakraborty et al., 2015)

Appearance

Sensory Quality								
Appearance						Triplet for Sensory Score		
	Poor	fair	good	Very good	excellent	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
S1A	2	5	7	2	0	39.0625	21.875	25
S2A	0	2	8	4	2	56.25	25	25
S3A	0	4	8	2	2	50	25	25
S4A	1	4	7	3	1	46.875	23.4375	25
S5A	3	2	9	1	1	40.625	20.3125	25
S6A	0	4	8	4	0	50	25	25
S7A	0	2	6	6	2	59.375	25	25
S8A	2	1	7	5	1	51.5625	21.875	25
S9A	1	2	7	6	0	53.125	23.4375	25
S10A	0	3	6	6	1	56.25	25	25
S11A	0	4	7	4	1	51.5625	25	25
S12A	1	5	5	3	2	46.875	23.4375	25

Flavour

Sensory Quality								
FLAVOUR						Triplet for Sensory Score		
	Poor	fair	good	Very good	Excellent	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
S1F	3	6	6	1	0	32.8125	20.3125	25
S2F	2	7	6	1	0	34.375	21.875	25
S3F	1	8	5	2	0	37.5	23.4375	25
S4F	1	4	8	2	1	45.3125	23.4375	25
S5F	0	3	8	3	2	53.125	25	25
S6F	1	4	7	4	0	46.875	23.4375	25
S7F	0	3	6	6	1	56.25	25	25
S8F	2	1	7	5	1	51.5625	21.875	25
S9F	1	3	7	5	0	50	23.4375	25
S10F	1	4	8	4	0	50	25	26.5625
S11F	2	6	6	2	0	37.5	21.875	25
S12F	2	4	7	3	0	42.1875	21.875	25

Taste

Sensory Quality								
TASTE						Triplet for Sensory Score		
	Poor	fair	good	Very good	Excellent	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
S1T	1	6	5	3	1	43.75	23.4375	25
S2T	0	6	8	2	0	43.75	25	25
S3T	2	8	6	0	0	31.25	21.875	25
S4T	0	4	7	5	0	51.5625	25	25
S5T	0	3	8	3	2	53.125	25	25
S6T	0	3	6	4	3	56.25	25	25
S7T	0	6	4	5	1	50	25	25
S8T	0	2	3	8	3	64.0625	25	25
S9T	1	3	6	6	1	56.25	25	26.5625
S10T	0	4	7	4	1	51.5625	25	25
S11T	1	5	7	2	1	43.75	23.4375	25
S12T	1	6	6	2	1	42.1875	23.4375	25

Aroma

Sensory Quality								
AROMA						Triplet for Sensory Score		
	Poor	fair	good	Very good	Excellent	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
S1Ar	0	2	8	4	2	56.25	25	25
S2Ar	0	4	6	5	1	53.125	25	25
S3Ar	0	6	6	4	0	46.875	25	25
S4Ar	0	0	5	8	3	67.1875	25	25
S5Ar	0	1	5	6	4	64.0625	25	25
S6Ar	0	1	7	6	2	60.9375	25	25
S7Ar	0	2	2	9	3	65.625	25	25
S8Ar	0	0	4	9	3	68.75	25	25
S9Ar	0	3	4	7	2	59.375	25	25
S10Ar	0	3	3	8	2	60.9375	25	25
S11Ar	0	3	5	7	1	57.8125	25	25
S12Ar	0	4	5	5	2	54.6875	25	25

Texture

Sensory Quality								
TEXTURE						Triplet for Sensory Score		
	Poor	fair	good	Very good	Excellent	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
S1Te	0	2	6	7	1	59.375	25	25
S2Te	1	3	8	4	0	48.4375	23.4375	25
S3Te	2	5	7	2	0	39.0625	21.875	25
S4Te	1	4	5	5	1	50	23.4375	25
S5Te	0	2	6	6	2	59.375	25	25
S6Te	2	4	5	3	2	45.3125	21.875	25
S7Te	0	6	6	4	0	46.875	25	25
S8Te	0	2	8	5	1	56.25	25	25
S9Te	1	5	7	4	0	48.4375	25	26.5625
S10Te	0	6	5	4	1	48.4375	25	25
S11Te	1	6	7	2	0	40.625	23.4375	25
S12Te	2	4	5	4	1	45.3125	21.875	25

Table. Sum of number of judges giving their preference for quality attributes of bread in general and the triplets corresponding to that score

						Triplet for sensory score			Triplet for relative weightage		
QUALITY ATTRIBUTE	NI	SI	I	HI	EI	X-COORDINATE	Y-COORDINATE	Z-COORDINATE			
Appearance	0	6	5	3	2	48.4375	25	25	0.161458	0.083333	0.083333
Flavour	1	2	4	7	1	53.125	21.875	23.4375	0.177083	0.072917	0.078125
Test	0	0	3	9	4	70.3125	25	25	0.234375	0.083333	0.083333
Aroma	0	2	5	5	4	60.9375	25	25	0.203125	0.083333	0.083333
Texture	0	1	3	10	2	67.1875	25	25	0.223958	0.083333	0.083333

Where, NI- Not at all important, SI- Somewhat important, I- Important, HI- Highly important, EI- Extremely important

s1	0	0	0	0.24715	0.717563	0	0	0	0	0
s2	0	0	0	0.279236	0.714399	0	0	0	0	0
s3	0	0	0	0.967692	0.057753	0	0	0	0	0
s4	0	0	0	0	0.742097	0.273101	0	0	0	0
s5	0	0	0	0	0.515833	0.4875	0	0	0	0
s6	0	0	0	0	0.787022	0.23038	0	0	0	0
s7	0	0	0	0	0.498397	0.523101	0	0	0	0
s8	0	0	0	0	0.065657	0.906013	0	0	0	0
s9	0	0	0	0	0.644499	0.385957	0	0	0	0
s10	0	0	0	0	0.680288	0.351212	0	0	0	0
s11	0	0	0	0.373064	0.617089	0	0	0	0	0

s12	0	0	0	0.342734	0.628956	0	0	0	0	0

Table 13: Overall membership function values of various sample

	F1	F2	F3	F4	F5	F6
S1	0	0.123575	0.964713	0.358781	0	0
S2	0	0.139618	0.993635	0.3572	0	0
S3	0	0.483846	1.025445	0.028877	0	0
S4	0	0	0.878648	0.64415	0	0
S5	0	0	0.759583	0.745417	0	0
S6	0	0	0.902212	0.623891	0	0
S7	0	0	0.759948	0.7723	0	0
S8	0	0	0.518664	0.938842	0	0
S9	0	0	0.837478	0.708207	0	0
S10	0	0	0.855894	0.691356	0	0
S11	0	0.186532	0.990153	0.308545	0	0
S12	0	0.171367	0.97169	0.314478	0	0

Table 14: Similarity values of bread sample and their ranking, where F1= Not satisfactory, F2= Fair, F3= Satisfactory, F4= Good, F5= Very Good, F6= Excellent

7. Process Selection

The Process was selected, keeping in mind a general process, irrespective of the type of legume that was used. The entire process was split into two main parts, the first part being, milling the legume, in order to homogenize it with the wheat flour.

7.1. Milling

A standard hammer mill is used for operation, with a number of hammer mills (ideally four to five), hinged on a central shaft, and also enclosed with a rigid metal case. The central hammer consists of a steel ganged hammer, which rotates at a high speed inside the chamber and causes size reduction of the legume through impact. (Hammer Mill, 2018)

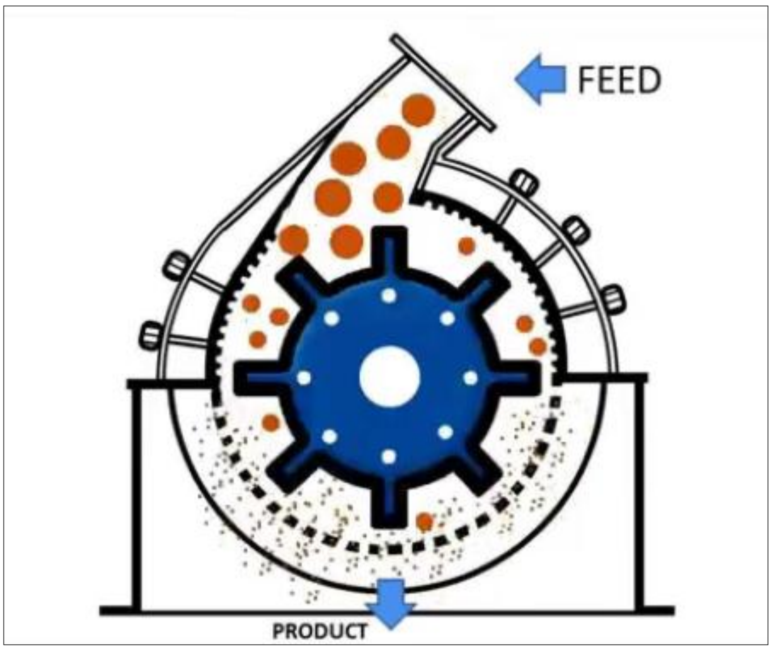


Figure 8: Industrial Hammer Mill

The continuous rotating action causes brittle fracture of the legume, which is in turn caused by the high angular velocity. The size reduction happens in two steps, firstly, by the dynamic impact and second, by attrition and shear.

The intended particle size is controlled through controlling the parameters of Feed Rate, RPM Speed and other factors such as shaft diameter, clearance, etc which has been explicitly designed in the later part of the report.

There are two main types of hammer mills, reversible and non-reversible. Both these are based on the direction of the rotor (clockwise, anticlockwise or both), depending on the requirement, however, their grinding mechanism and action remains the same.

Hammer mills have a very rampant milling action, which makes it suitable in grinding the legume and turning it into flour. The main advantages of a hammer mill are: (Chikelu C.C., 2015)

- High reduction ratio and high milling capacity, suitable for industrial uses
- Easy to operate and modular construction
- Easy to maintain and clean
- Cost is low
- Lower cost of manufacturing

7.2. ***Dough Mixer***

The dough mixers are classified on the basis of: (Types of Dough Mixer, 2019)

1. Size requirement: The capacity of the mixing bowl is fixed based on the capacity
2. Automated or semi-automated
3. Heavy or light
4. Batch or continuous mixers

For the manufacture of 1500 kg/day of bread, the mixing operation is to be done in a batch manner, with 10 hours of operation. For batch mixers, there are two major types:

7.2.1. ***Vertical, detachable bowl mixers***

In this type of mixer, the beaters are mounted vertically on an axle, and they rotate on a fixed position and rotate on a circular, planetary manner. The beater speed can be decided on the basis of requirement, for, if the size requirement is small, faster mixing is possible due to higher RPM, whereas, for larger size, the RPM needs to be reduced.

Advantages:

1. The dough mixtures which are to be fermented or remixed can be left in the tub without additional effort

2. As the number of beaters and mixing action can be varied, different mixing actions can be achieved
3. It is easier to visually monitor the state of mixing
4. It is easier to manually charge the bowl and is mobile

Disadvantages:

1. The mixing achieved is not uniform in certain cases. This can result in lesser development of some parts of the dough
2. Difficult to maintain the temperature of the bowl, and thus, involves installation of additional water cooling jackets
3. Longer mixing times (45 minutes)

Figure 9: Detachable bowl mixers

7.2.2. ***Horizontal High Speed Mixers***

In case of a horizontal high speed mixer, the bowl is fixed to its base, where an entry door allows the entry and discharge of the dough. The beaters are attached to the side and are fixed to one or two of the shafts. The shape of the mixing bowl depends on the number of blades on the beater and number of impellers. The two subtypes are:

1. Single shaft high speed mixer
2. Z blade twin horizontal high speed mixer

Advantages:

1. These are very powerful mixers due to the bearings on its sides and is able to procure tougher dough in faster times than a vertical mixer
2. There is a better and accurate temperature control through a jacket with constant water circulation or refrigerant
3. The ingredients can be added through the top while the mixing is in operation

Disadvantages:

1. Charging the mixing chamber takes a longer time
2. The rapid action causes the beaters to throw up material vertically, leading to blind spots
3. The progress of the mixing cannot be well monitored
4. The beating action can cause extensive vibration
5. Lesser mobility as compared to the vertical mixer

Figure 10: i) Single shaft high speed mixer ii) Z blade twin horizontal high speed mixer

Based on the assessment of the available options in choosing a dough mixer, the **Vertical, detachable bowl mixer** was chosen as:

- As the mixing can be monitored at stages, the progress of the mixing can be kept under control

- Mobility plays a big role, as the plant requires manufacture of three different types of legumes, and hence, the bowls can be interchanged to be used for either of the legumes
- Easier cleaning would lead to lesser effort, as the same mixer can be used for multiple operations
- There are two stages of mixing involved, the First Mixing and Second Mixing (Post Fermentation). A vertical detachable bowl mixer can be used for both the operations, just by replacing the mixing bowl.
- The capacity of the plant is comparatively lower in terms of mixing. Thus, it would prove to be quite economical.

5.3. Fermentation Chamber

The method used for fermentation of bread, is the direct fermentation process. Although the shelf life of the bread would be lower, the fermentation time is much less, and thus can be used as an advantage. The quick manufacture of bread would thus reduce the time of retardation. The dough would thus be kneaded, rested, proved and then baked immediately. The fermentation conditions can be based on the standard protocol. (Bread fermentation methods, 2019)

Certain factors influencing the fermentation process are the duration of kneading, quantity of yeast, fermentation conditions, type of flour, quantity of salt and sugar, quantity of emulsifier, proving time

Figure 11: Fermentation Chamber

The kneading operation is done using the commercial dough kneading machine, and does not involve much of complexity.

5.4. Baking Oven

A standard convective oven is used for baking the fermented dough. The conditions of the baking oven are decided based on the standard protocol. A general baking temperature of around 180-220^{o}C is used to bake the dough and procure a final product. The mixing time is generally fixed at any range from 30-90 minutes based on requirement. The modeling of the same has been done in the later part of the report.

The surface temperature of the bread depends on a number of factors such as:

- Density of the flour
- Length of the bread loaf
- Radius of the bread crumb
- Ambient oven temperature
- Specific heat capacity of air

In most industrial cases, there is an attached sheeter attached to the baking oven, in order to directly obtain the cut loaves of the bread.

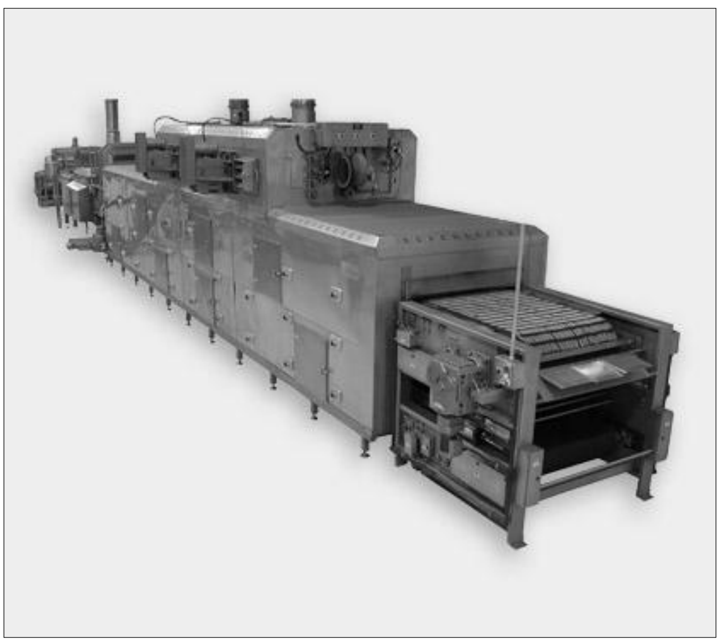


Figure 12: Industrial Baking Oven

6. H&MB Modeling of Baking Conditions

As a measure of trying to predict the behavior of two critical parameters affecting the baking process, a model was established to find a correlation between the behavior of 'Surface Temperature of the Bread during Baking' and the 'Water content of the bread with time, as a function of the surface temperature'.

The modeling was done using the standard laws of Heat and Energy Balances, with the graphs being analyzed using the *Python Programming language*. For simplicity, the bread is modeled as a system having three zones: (Khater & Bahnasawy, 2014)

1) Crumb, which is the wetter inner zone which is devoid of dehydration and the surface temperature stays at 100°C
2) Crust, is the dry outer zone, wherein the temperature can exceed 100°C along with loss of water
3) Evaporation zone, serves as the equilibrium zone between the crumb and crust where the temperature remains constant (100°C, which is the boiling point of water at normal conditions).

Certain underlying assumptions make way for establishing the behavior between the properties:

- The bread is homogenous and continuous
- The impurities present (if any) in the bread do not affect the nature of the curve
- The major contribution to the total heat transferred is by radiation and convection (from the oven surface to bread)
- Heat transfer due to conduction is negligible as compared to that by radiation and convention. This mode of heat transfer would only affect the temperatures inside the bread surface which is insignificant
- Volume is assumed to be constant for the entire course of baking
- The bread is assumed to be of cylindrical shape (similar to a loaf)
- The water vapor migration happens from the core to the evaporation front under a water gradient and follows the Fick's diffusion law
- Water transfer takes place through convective flux

- Water activity is assumed to be unity

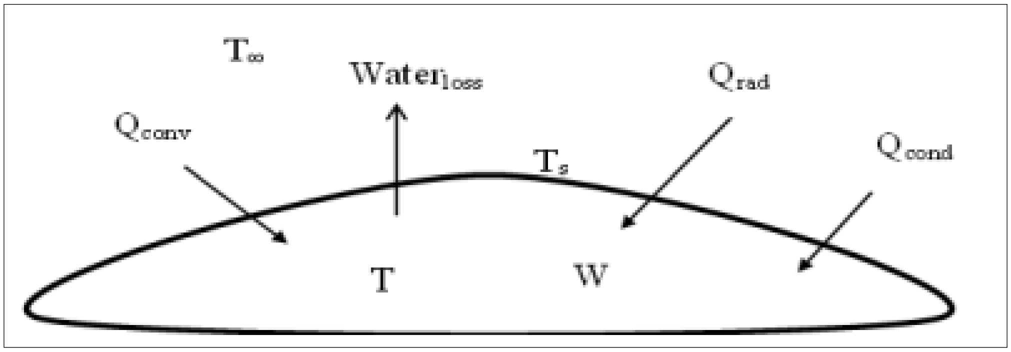


Figure 13: Modeling to understand the heat and mass balance

The certain parameters involved in defining the model are:

Q_{total}: Net heat transferred

$Q_{conduction}$: Net heat transferred due to conduction

$Q_{convection}$: Net heat transferred due to convection

$Q_{radiation}$: Net heat transferred due to radiation

T_s: Surface Temperature of the Bread

T_{inf}= Ambient Temperature inside the oven (Steady State)

T_0= Initial Temperature of Bread before baking

W: Moisture content at time t

W_o=Initial water content

6.1. ***Modeling of Surface Temperature with Time***

The governing equation used for the same is: (M.Marcotte, 2007)

$Q_{total} = Q_{conduction} + Q_{convection} + Q_{radiation}$

Subsequently,

$$Q_{total} = \rho * V * C_p * \frac{\partial T}{\partial t}$$

Where $\rho$the density of the flour, V is is the volume of the bread, C_p is the specific heat of ambient air

$Q_{conduction}$=0 (assumption)

$Q_{convection} = -h * A * (T - T_{inf})$

Where, h is the effective heat transfer coefficient (=4 $W/m^2/K$), A is the heat transfer area

$Q_{radiation} = -\in * \sigma * A * \left(T^4 - T_{inf}^4\right)$

Where, $\in$ is the emissivity, σ is the Stephan Boltzmann Constant

The combined equation is as follows:

$$\rho * V * C_p * \frac{\partial T}{\partial t} = -h * A * \left(T - T_{inf}\right) + -\in * \sigma * A * \left(T^4 - T_{inf}^4\right)$$

The following is a first order partial differential function, which is solved using the Python program and the model is thus obtained. For the reason, the volume and area are obtained using the standard dimensional formula for a cylinder. Data used:

Table 15: Data used for Modeling

Bread Density	511	kg/m3
emissivity	0.9	
Bread radius	0.07	m
Stephan Boltzmann constant	5.68E-08	$W\ m^{-2}\ K^{-4}$
Ambient temperature	473	K
Heat transfer coefficient	4	$W\ m^{-2}\ K^{-1}$
Initial Temperature	293.16	K
length of loaf	0.2159	m
cp air	1000	J/kg/K

Area of heat transfer, $A = 2 * \pi * R * L$

Volume of bread, $V = \pi * R^2 * L$

6.1.1. Surface Temperature Profile of bread

The python code (Refer Annexure) was thus run to completion and a curve for temperature versus time for the ambient condition assumed was computed and the result was as follows:

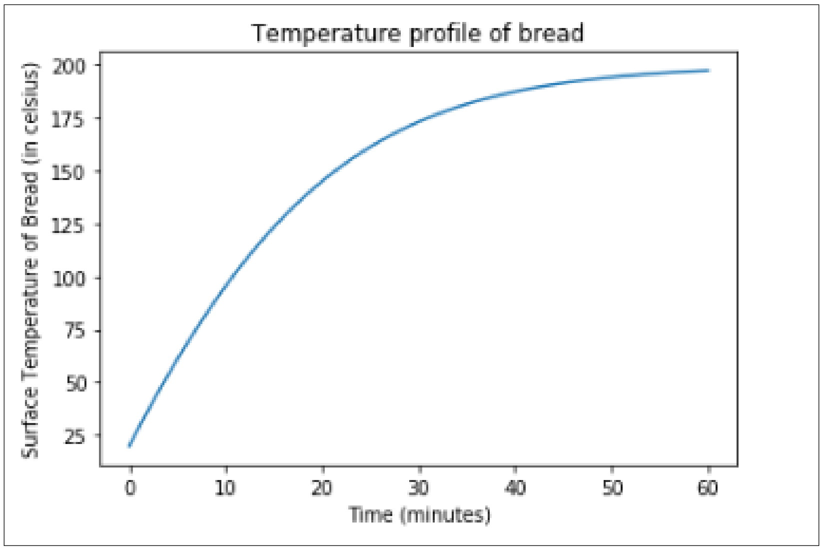


Figure 14: Graph of Surface Temperature versus time

From the nature of curve, it is observed that the temperature of the bread increases with the baking time, meeting the required expectations. Moreover, it can also be observed that the surface temperature of the bread reaches a degree of around 180^{o} Celsius.

In order to estimate a model, a third degree polynomial was fitted using the curve fit function and the equation thus obtained was:

$$T=4.82\times10^{-9}\times t^{3} -4.6*10^{-5}\times t^{2}+ 0.15\times t+ 292.7$$

The fitted curve matched exactly, with R^2=0.99, thus giving out a satisfactory data.

6.1.2. Varying the Oven Ambient Temperature

To analyze the effect of oven ambient temperature on the temperature profile, three temperatures (180,200 and 220) were chosen and its effect on the temperature profile was simulated.

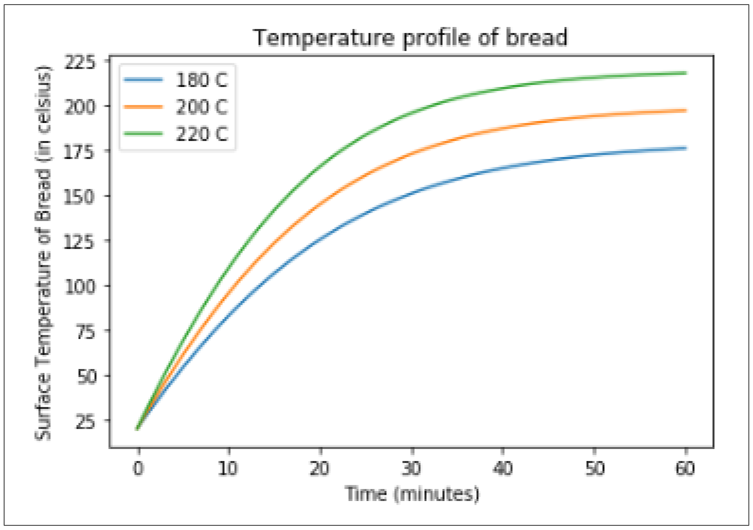


Figure 15: Graph of Surface temperature versus time for varying oven ambient temperatures

From the plot, it becomes explicitly clear that, as the oven ambient temperature is increased, there is a faster increase in the temperature of the bread inside the oven.

6.2. Modeling of Moisture Content with Time

The modeling of the moisture content was done in a similar manner using the Python language. It was based on the principle of mass conservation.

Mathematically,

$$-D \times \rho \times \frac{\partial W}{\partial t} = k_g \times (P_s \times T_s - P_{inf} \times T_{inf})$$

Where, D is the water diffusion coefficient and k_g is the mass transfer coefficient

These expressions are calculated as follows:

$$P_s = a_w \times P_{sat} \times T$$

Water activity,

$$\frac{1}{a_w} = \left(\frac{100W}{\exp\left(-0.0056 \times T + 5.5\right)}\right)^{\frac{-1}{0.38}} + 1$$

$$P_{inf} = \frac{RH}{100} \times P_{sat} \times T_{inf}$$

Data used:

Table 16: Data used for the calculation of loss of moisture

Mass of air	28.84	g
Mass of water	18	g
Kinematic viscosity	28.86*10^-6	m^2/s
Thermal diffusivity	1.17*10^-7	m^2/s
Saturated pressure	1	atm
% RH	10	
Diffusion coefficient	10^-4	m^2/s

6.2.1. Calculation of Mass Transfer Coefficient

Schmidt Number, $Sc = \frac{v}{D}$

Calculating, Sc=0.288

Prandtl Number, $Pr = \frac{v}{\alpha}$

Calculating, Pr=246.66

Using standard correlation for mass transfer coefficient,

$$\frac{h}{k_g} = \frac{M(air)}{M(water)} \times P_{atm} \times C_p \times \left(\frac{Sc}{\mathrm{Pr}}\right)^{2/3}$$

From the correlation, all values are substituted.

We get, **k_g=0.0132 m^2/s**

The python code (Refer Annexure) was thus run to completion and a curve for moisture content vs time for the ambient condition assumed was computed and the result was as follows:

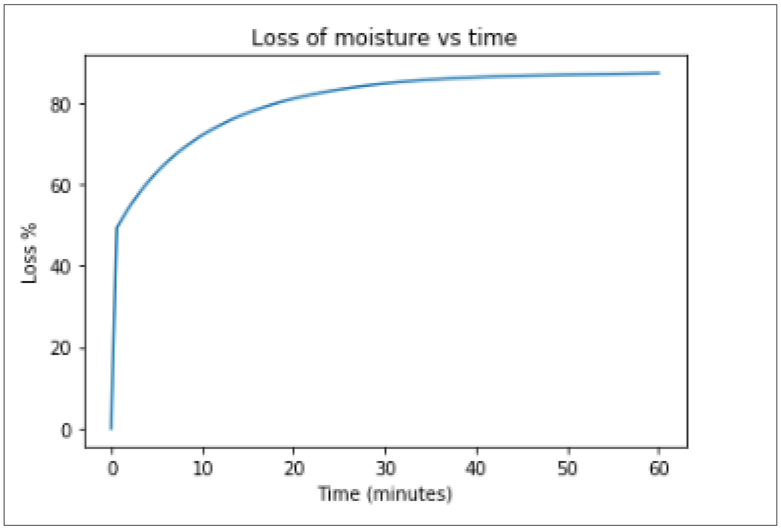


Figure 16: Graph of loss of moisture versus time

From the curve, it can be inferred that there is a rapid decrease in the water content within the initial few minutes. This can be attributed to the low water activity initially. As the time of baking progresses, there is an increase in the temperature of the bread. The temperature, in turn influences the water activity.

7. Mechanical Design

7.1. Design of Hammer Mill

Particle size reduction is an important exercise in the manufacture of bread. Presently, in relevance to the project, the hammer mill is used to reduce the particle size for the legumes used, which are thereby mixed with the wheat flour and yeast, in order to ensure proper mixing in the mixing chamber, which is then, thereby taken to the fermentation. (Hanafi A Radwan, 2015)

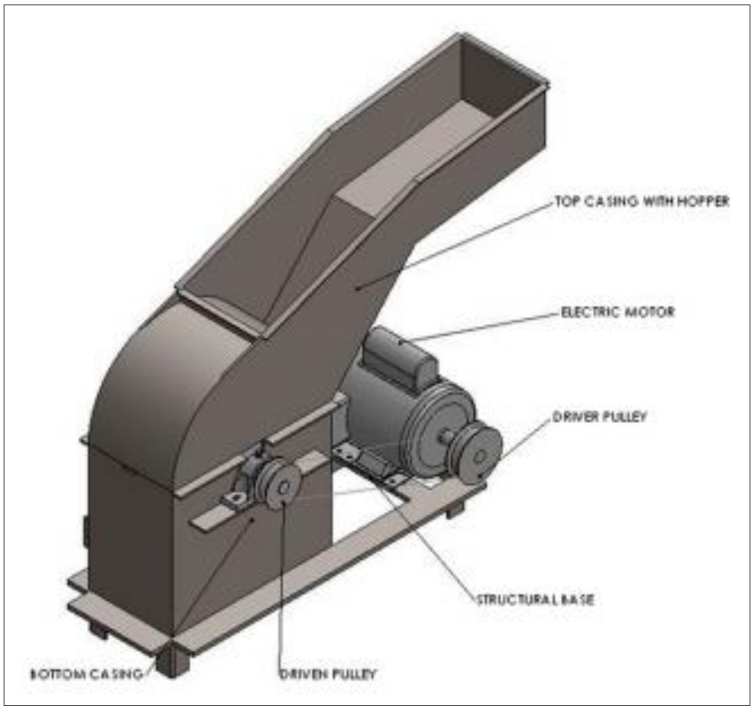


Figure 17: Industrial Hammer Mill

7.1.1. Construction of a hammer mill

From literature, the standard procedure for the construction of a hammer mill is followed, which is used to calculate parameters such as tensions in the pulleys and finally, the power required. Although in literature, the procedure is followed for small scale hammer mill, as per the requirement of the project, the dimensions of the hammer mill are then scaled up. Correspondingly, the power required is calculated and then quantified economically. (Anthony)

Standard Assumed Data:

Table 17: Assumed data for the designing of the hammer mill

Diameter of motor pulley	0.09	m
Diameter of shaft pulley	0.07	m
Revolution of motor pulley	1500	rpm
Centre to centre distance	490	mm
Mass of hammer	0.2	kg
Radius of Shaft	25	mm
Width of belt	0.013	m
Thickness of belt	0.008	m
Belt Density	1140	kg/m3
Coefficient of Friction	0.2	
Standard Length of Mill	0.8	m
Standard Width of Mill	0.3	m
Height of Mill	0.2	m

7.1.2. Shaft Speed Determination

For consistency,

$$\frac{N_1}{D_1} = \frac{N_2}{D_2}$$

Where, N_1= Revolution of motor pulley, N_2= Revolution of shaft pulley, D_1=Diameter of motor pulley, D_2= Diameter of shaft pulley.

Substituting, we get,

RPM of Shaft Pulley, $N_2 = \frac{1500\times0.07}{0.09}$ = 1166.67 rpm

7.1.3. Length of Belt

The length of conveyer belt depends upon the centre to centre distance and the diameters.

$$L = 2 * C + \frac{\pi}{2} \times (D_1 + D_2) + \frac{(D_1 - D_2)^2}{(4 \times C)^2}$$

From this, the Length of the belt was calculated as follows,

$$L = 2 \times 490 + \frac{\pi}{2} \times (90 + 70) + \frac{(90-70)^2}{(4\times490)^2} = 1231.39 \text{ mm}$$

7.1.4. Belt Contact Angle Determination

$Contact\ angle = \sin^{-1}(\frac{R-r}{C})$

$\beta = \sin^{-1}(\frac{45-35}{490})$ = 0.0204 radians

$\beta = 1.17\ degrees$

Angles of wrap are evaluated as follows:

$\alpha = 180 - 2 \times \beta$ (for Shaft Pulley)

$\alpha = 180 + 2 \times \beta$ (for Motor Pulley)

Angle of wrap for motor	182.3387664	degrees
Angle of wrap for shaft	177.6612336	degrees

7.1.5. Centrifugal Force exerted by hammer

Weight of hammer, $W = mass\ of\ motor \times 9.81$

W= 1.962 N

Shaft Velocity, $V = \frac{\pi\times D_1\times N_1}{60}$

$$V = \frac{\pi\times0.09\times1500}{60} = 7.065 \text{ m/s}$$

Thus, the Centrifugal Force on hammer is:

$$F = \frac{M \times V^2}{R}$$

Calculating,

$$F = \frac{0.2 \times 7.065^2}{0.0125} = 798.268\ N$$

7.1.6. Estimation of Belt Tensions

Mass per unit length, $M = Width\ of\ belt \times Thickness\ of\ belt \times Belt\ density$

$$M = 0.013 \times 0.008 \times 1140 = 0.11856 \text{ kg/m}$$

Thus, the centrifugal tension is: $T_c = M \times V^2$

$$T_c = 0.01856 \times 7.065^2 = 5.92 \text{ N}$$

By standard procedure,

Tension in the tight side of the pulley, $T_1 = 3 \times T_c$

Calculating, $T_1 = 17.75\ N$

For the tension in the slack side,

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\theta \times \mu}$$

Substituting for T_1, θ, μ and Solving for T_2

Thus, tension in the slack side **T_2= 8.83 N**

7.1.7. Power Calculation

Power Required = $(T_1+T_2)\times V$

Thus, Power required = 187.79 W

7.1.8. Dimension Scale-up

The above calculations are carried out, on the basis that, the workability is 30 kg/hr. However, the hammer mill operational for the project under consideration is 150 kg/hr. Thus, the dimensions of the hammer mill are needed to be scaled up.

In order to design the same for the required capacity, there are some underlying assumptions,

1. The dimensions and RPM of the pulleys remains the same
2. The length of the conveyer belt remain the same
3. Hammer weight remains considerably same
4. Shaft Radius is unchanged, which leads to no change in the Shaft velocity
5. The scale-up increase of dimensions of length, breadth and height increases by the same factor
6. The dimensions of the belt increases by the same factor

Assuming that each of length, breadth and height are increased by a factor, ‘k’.

$$V_{old} = L \times B \times H$$

$$V_{scaled-up} = k^3 \times L \times B \times H$$

The flow rate was thus varied for a multiple values, in order to generalize the situation and then apply it to the current flow.

Table 18: Dimension scale up based on capacity

Sr. No.	Capacity (kg/hr)	Flow (m3/hr)	Factor	Length	Width	Height	Volume
1	31	0.05228	1.02886	0.8	0.3	0.2	0.048
2	50	0.08432	1.20659	0.96527	0.361976	0.24132	0.08432
3	75	0.12648	1.3812	1.10496	0.414359	0.27624	0.12648
4	100	0.16863	1.5202	1.21616	0.456061	0.30404	0.16863
5	125	0.21079	1.63759	1.31007	0.491276	0.32752	0.21079
6	150	0.25295	1.7402	1.39216	0.522059	0.34804	0.25295
7	175	0.29511	1.83195	1.46556	0.549586	0.36639	0.29511
8	200	0.33727	1.91533	1.53227	0.5746	0.38307	0.33727
9	225	0.37943	1.99203	1.59362	0.597609	0.39841	0.37943
10	250	0.42159	2.06323	1.65059	0.61897	0.41265	0.42159
11	275	0.46374	2.12983	1.70387	0.63895	0.42597	0.46374
12	300	0.5059	2.19251	1.75401	0.657753	0.4385	0.5059

13	325	0.54806	2.2518	1.80144	0.675539	0.45036	0.54806
14	350	0.59022	2.30811	1.84649	0.692434	0.46162	0.59022
15	375	0.63238	2.36181	1.88945	0.708543	0.47236	0.63238
16	400	0.67454	2.41317	1.93054	0.723951	0.48263	0.67454
17	425	0.71669	2.46243	1.96995	0.73873	0.49249	0.71669
18	450	0.75885	2.5098	2.00784	0.75294	0.50196	0.75885
19	475	0.80101	2.55544	2.04435	0.766632	0.51109	0.80101
20	500	0.84317	2.59951	2.07961	0.779853	0.5199	0.84317
21	525	0.88533	2.64213	2.11371	0.79264	0.52843	0.88533
22	550	0.92749	2.68342	2.14674	0.805026	0.53668	0.92749
23	575	0.96965	2.72348	2.17878	0.817044	0.5447	0.96965
24	600	1.0118	2.76239	2.20991	0.828717	0.55248	1.0118
25	625	1.05396	2.80024	2.24019	0.840071	0.56005	1.05396
26	650	1.09612	2.83709	2.26967	0.851126	0.56742	1.09612
27	675	1.13828	2.873	2.2984	0.861901	0.5746	1.13828
28	700	1.18044	2.90804	2.32643	0.872413	0.58161	1.18044
29	725	1.2226	2.94226	2.35381	0.882677	0.58845	1.2226
30	750	1.26476	2.9757	2.38056	0.892709	0.59514	1.26476
31	775	1.30691	3.0084	2.40672	0.902519	0.60168	1.30691
32	800	1.34907	3.0404	2.43232	0.912121	0.60808	1.34907
33	825	1.39123	3.07175	2.4574	0.921525	0.61435	1.39123
34	850	1.43339	3.10247	2.48198	0.930741	0.62049	1.43339
35	875	1.47555	3.13259	2.50607	0.939778	0.62652	1.47555
36	900	1.51771	3.16215	2.52972	0.948644	0.63243	1.51771
37	925	1.55987	3.19116	2.55293	0.957348	0.63823	1.55987
38	950	1.60202	3.21965	2.57572	0.965896	0.64393	1.60202
39	975	1.64418	3.24765	2.59812	0.974296	0.64953	1.64418
40	1000	1.68634	3.27518	2.62014	0.982553	0.65504	1.68634

$$Belt\ width_{scaled-up} = k \times Belt\ width_{old}$$

$$Belt\ thickeness_{scaled-up} = k \times Belt\ thickness_{old}$$

From this, the Mass per unit length and the corresponding tensions are calculated. Further, the Power is estimated for each capacity.

Table 19: Estimation of Power based on Capacity

Sr. No.	Capacity (kg/hr)	Thickness belt	M	T_c	T_{tight}	T_{slack}	Power
1	31	0.008	0.119	5.918	17.75	8.827	187.8
2	50	0.01	0.173	8.615	25.85	12.85	273.4
3	75	0.011	0.226	11.29	33.87	16.84	358.2
4	100	0.012	0.274	13.68	41.03	20.4	434
5	125	0.013	0.318	15.87	47.61	23.67	503.6
6	150	0.014	0.359	17.92	53.76	26.73	568.7
7	175	0.015	0.398	19.86	59.58	29.62	630.2
8	200	0.015	0.435	21.71	65.13	32.38	688.9
9	225	0.016	0.47	23.48	70.45	35.03	745.2
10	250	0.017	0.505	25.19	75.58	37.58	799.4
11	275	0.017	0.538	26.84	80.53	40.04	851.9
12	300	0.018	0.57	28.45	85.34	42.43	902.7
13	325	0.018	0.601	30.01	90.02	44.76	952.2
14	350	0.018	0.632	31.53	94.58	47.02	1000
15	375	0.019	0.661	33.01	99.03	49.24	1048
16	400	0.019	0.69	34.46	103.4	51.4	1094
17	425	0.02	0.719	35.88	107.6	53.52	1139
18	450	0.02	0.747	37.28	111.8	55.6	1183
19	475	0.02	0.774	38.65	115.9	57.64	1226
20	500	0.021	0.801	39.99	120	59.65	1269
21	525	0.021	0.828	41.31	123.9	61.62	1311
22	550	0.021	0.854	42.61	127.8	63.56	1352
23	575	0.022	0.879	43.89	131.7	65.47	1393

24	600	0.022	0.905	45.16	135.5	67.36	1433
25	625	0.022	0.93	46.4	139.2	69.22	1473
26	650	0.023	0.954	47.63	142.9	71.05	1512
27	675	0.023	0.979	48.85	146.5	72.86	1550
28	700	0.023	1.003	50.05	150.1	74.65	1588
29	725	0.024	1.026	51.23	153.7	76.41	1626
30	750	0.024	1.05	52.4	157.2	78.16	1663
31	775	0.024	1.073	53.56	160.7	79.89	1700
32	800	0.024	1.096	54.7	164.1	81.6	1736
33	825	0.025	1.119	55.84	167.5	83.29	1772
34	850	0.025	1.141	56.96	170.9	84.96	1808
35	875	0.025	1.163	58.07	174.2	86.62	1843
36	900	0.025	1.186	59.17	177.5	88.26	1878
37	925	0.026	1.207	60.26	180.8	89.89	1912
38	950	0.026	1.229	61.35	184	91.5	1947
39	975	0.026	1.25	62.42	187.3	93.1	1981
40	1000	0.026	1.272	63.48	190.4	94.68	2014

In order to find a general co-relation, a graph was plotted and a power equation was thus fitted.

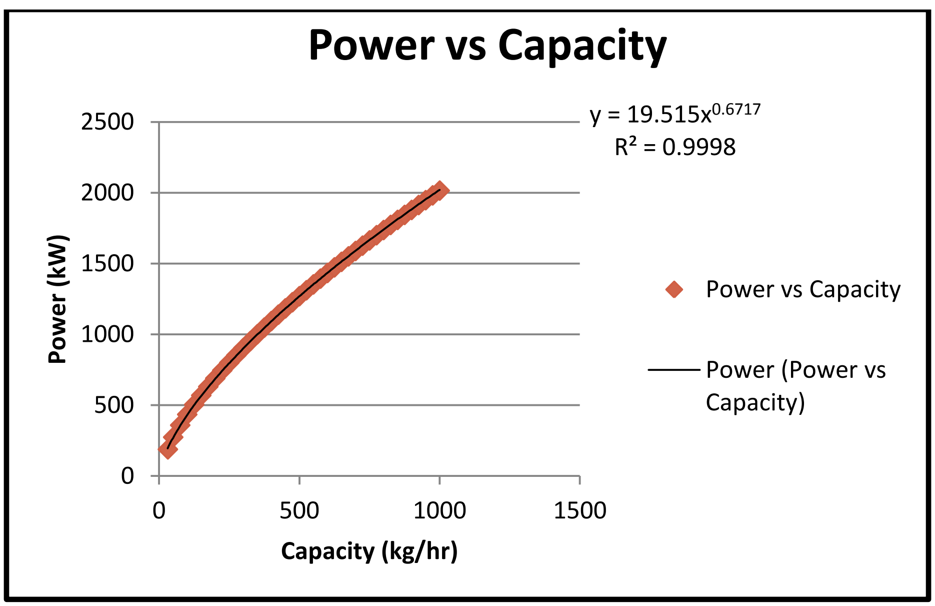


Figure 18: Plot of Power versus Capacity for a Hammer mill

7.2. Design of Dough Mixer

7.2.1. Design Considerations

The major designs of an industrial dough mixer are on the mixing basin, power requirement; reducer gear; pulley; belt drive; flat collar bearings; cross-ribbon; andthe following equations were used to design the unit parts.

Figure 19: Industrial Dough Mixer

7.2.2. Volume of Mixing Basin

In designing for a mixer capable of mixing 150 kilograms of flour per batch of 1 hour at 1 atmosphere pressure (101325 N/m^2) mixing pressure, 1500 rpm ribbon speed, 1.097 g/cm^3 dough density is used to calculate the dough density (Campbell et. Al 1993).

$$Dough\ Volume\ (V_d) = \frac{m_d}{\rho_d}$$

Where, $V_d = Volume\ of\ the\ dough\ (m^3), m_d = mass\ of\ the\ dough\ (kg),\ \rho_d = dough\ density\ (\frac{kg}{m^3})$

$$V_d = \frac{150}{1097}$$

$$= 0.137\ m^3$$

Assume volume of water + volume of air space + other ingredients = 25%. Thus, Volume of mixing basin, V_b= 0.137 + (0.25 x 0.137) = 0.17125 m^3.

7.2.3. Diameter of the Mixing Basin

We have considered a cylindrical mixing basin, so the diameter of the mixing basin is given with the empirical relationship given below:

$$\text{Volume of the mixing basin } (V_b) = \frac{\pi \times {d_b}^2}{4} \times h_b$$

Let the height of the mixing basin be = 0.5 m. We know that $V_b = 0.171$ m^3.

Hence, the diameter of the mixing basin is,

$$d_b = \sqrt{\frac{4 \times V_b}{\pi \times h_b}}$$

$$d_b = \sqrt{\frac{4 \times 0.171}{\pi \times 0.5}}$$

= 0.659 m

7.2.4. Thickness of the Mixing Basin

The mixing basin is classified as an open end vessel with only the circumferential or hoop stress induced by the mixing pressure. This circumferential or hoop stress acts in a direction tangential to the circumference of the basin and thickness of mixing basin is determined with the expression by Khurmi and Gupta (2005).

$$t = \frac{p \times d}{2 \times \sigma}$$

Where t = thickness of mixing basin (m), p = the mixing pressure (N/m^2), d = internal diameter of mixing basin (m), and = circumferential or hoop stress for steel material.

$$t = \frac{16942 \ \times 0.171}{2 \times 2.5 \ \times 10^6}$$

= 0.0022 m = 2.2 mm, hence a 4 mm stainless steel thick plate is selected.

7.2.5. Power requirement

The power which the electric motor must develop to drive the mixer is determined with the expression by Khurmi and Gupta (2005).

$$Power = \frac{2 \times \pi \times N_m \times T_m}{60 \times \eta}$$

To find out the power, we need to find out the torque imparted by the impeller on the dough. We assume that each particle revolves with the same RPM.

$$Torque = \ m \times \omega^2 \times r^2$$

$$= 150 \times \frac{200^2}{60^2} \times \ \frac{0.659^2}{2^2}$$

$$= 181.44 \ Nm$$

Hence, Power required is,

$$Power = \ \frac{2 \times \pi \times 200 \times 181.44}{60 \times 0.9} = 4.2 \ kW$$

Therefore, the power required is 4.2 kW (5.65hp). Hence, an electric motor of 6hp 1440rpm is ideal.

7.2.6. Selection of Pulleys and Determination of their speeds

The gearbox pulley diameter is determined using the expression for pulley reduction efficiency

$$Pulley \ reduction \ efficiency = \ \frac{Output \ pulley \ rpm \ (N_2)}{Input \ Pulley \ rpm \ (N_1)} = \frac{Gear \ box \ pulley \ rpm \ (N_2)}{motor \ pulley \ rpm \ (N_1)}$$

For 50% reduction efficiency, 0.5 = $\frac{N_2}{N_1}$

$$N_2 \ = 0.5 \ \times \ N_1$$

$$= 0.5 \ \times 1440 = 720 \text{ rpm}$$

Hence, form the empirical relation,

$$\therefore \frac{N_2}{N_1} = \frac{d_1}{d_2}$$

$$d_2(gearbox\ pulley\ diameter) = \frac{N_1 \times d_1}{N_2}$$

$$= \frac{1440 \ \times d_1}{720}$$

Let $d_1 = 100mm$ (motor pulley diameter)

$$= 200\ mm$$

Also the centre distance (x) between the two pulleys was given by Khurmi and Gupta (2005),

$$x = \frac{d_1 + d_2}{2} + d_1$$

$$= \frac{100+200}{2} + 100 = 250\ mm$$

7.2.7. Gearbox Selection

For gearbox reduction speed selection, we need to calculate the gear reduction ratio,

$$Gearbox\ reduction\ ratio = \frac{Gearbox\ pulley\ speed\ (N_2)}{Mixer\ speed\ (N_m)}$$

$$= \frac{720}{200} = 3.6{:}\,1 \sim 4{:}\,1$$

$$Design\ Power\ = 1.25 \times 5.65$$

$$= 7.065\ hp$$

This indicates that for a 4/1 gear unit at 200 rpm output speed, a 5.65 hp motor is required.

7.2.8. Belt drive selection

Belt length (l) is determined based on the formula given by Khurmi and Gupta (2005),

$$L = \frac{\pi\times(d_1+d_2)}{2} + 2x + \frac{(d_1-d_2)^2}{4x}$$

$$L = \frac{\pi \times (100 + 200)}{2} + 2 \times 250 + \frac{(100 - 200)^2}{4 \times 250}$$

$$L = 981.23\ mm$$

The angle of contact of belt on the motor pulley $(\theta) = (180 - 2\alpha) \times \frac{\pi}{180}$

Where sinα = $\frac{d_2 - d_1}{x} = \frac{200-100}{250} = 0.4$

Thus, α= 23.58^{o}, hence $\theta = 2.32\ rad$

8. Process Control

Process Control is an integral part of the baking industry, so as to ensure that the bread prepared is wholesome, nutritious, healthy and safe. There are numerous sub-operations involved in the bread making process, ranging from milling, mixing, proofing, etc. Each of these operations requires their own set of control instruments and establishing control parameters.

There are two major types of measurements, categorized as on-line measurements and offline measurements. (Cauvain, 2015)

On-line measurements are difficult to carry out, mainly due to the nature of the bread making and baking process. The most important parameter controlled for the product is the weight of the bread piece or the weight of dough. Underweight or overweight products are automatically rejected and are sent back for correction. Moreover, the loaf height is also to be monitored, for if the loaf height is higher than that of the baking oven, there would be difficulties arising during the baking process. The shape and color of the crust is also controlled in modern bakeries using modern methods such as colorimetry and size-measurement methods.

Off-line measurements are mainly concerned with the pre-manufacturing quality of the raw materials and product quality (in terms of taste). These measurements are done through age old techniques and are found, in both traditional and modern bakeries alike.

Of all the involved operations, the most critical operation and that which requires the most scrutiny in terms of process control, is the Baking Process. There are four critical parameters which need to be controlled for a baking instrument, that being temperature, heat transfer, humidity and baking time. (Stear, 1990)

8.1. Temperature Control and Heat Transfer

The heat transfer for a baking oven takes place mainly by radiation; however convection and conduction do play a minor role. There are specified modifications for different types of ovens; there are some standard guidelines which are to be followed in order to facilitate effective process control: (Stear, 1990)

The oven should be utilized at the near maximum capacity

Final temperature and oven temperature should be in synchronization

Thermometers should be placed at specified places, checked and calibrated at regular intervals

All the openings (vents, steam valves and loading doors) should be kept open for a period indefinite

Prevent hotspot formation

To limit breakdown failures, regular checks are mandatory

The heat input for ovens is through gas, which serves as a popular heat energy source. The volume of gas-flow unit time is measured by a cylindrical-type digital counter, designed for various throughputs. The gas to air ratio must be kept under check, as minimum air is required for burning. Similarly, the electro-energy can be measured by a calibrated meter, measuring units consumed in kW-hr. (Schneeweiss & Klose, 1981)

To measure the heat transfer change by radiation or conduction, pyrometers can be installed, which works on the expansion principle. The changes in conduction are measured by studying the deformations in the bimetallic strip at various temperatures, whereas the radiation heat transfer changes are measured by changes in electrical resistance. Thermocouples can also be added, connected to the pyrometers by copper wires. Temperatures are measured within the various temperature zones, burner space and the circulation system.

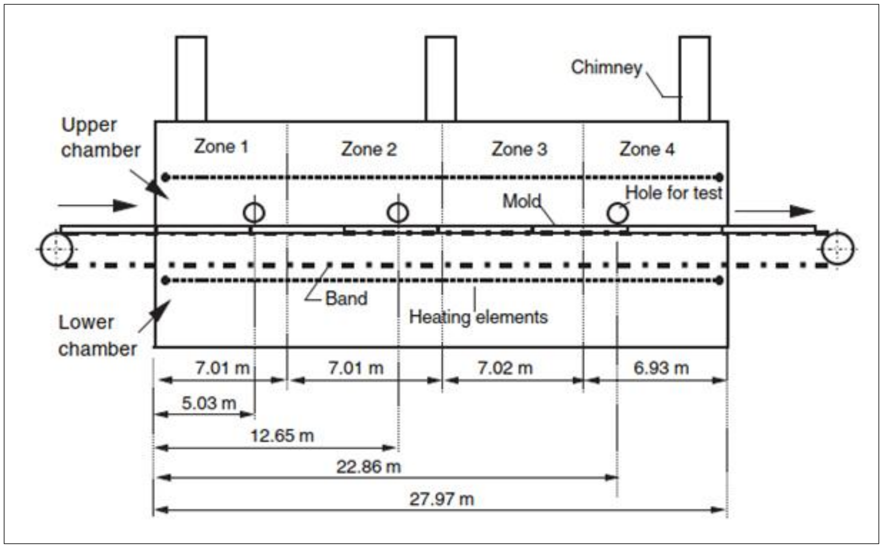


Figure 20: Zones in elctric fired oven

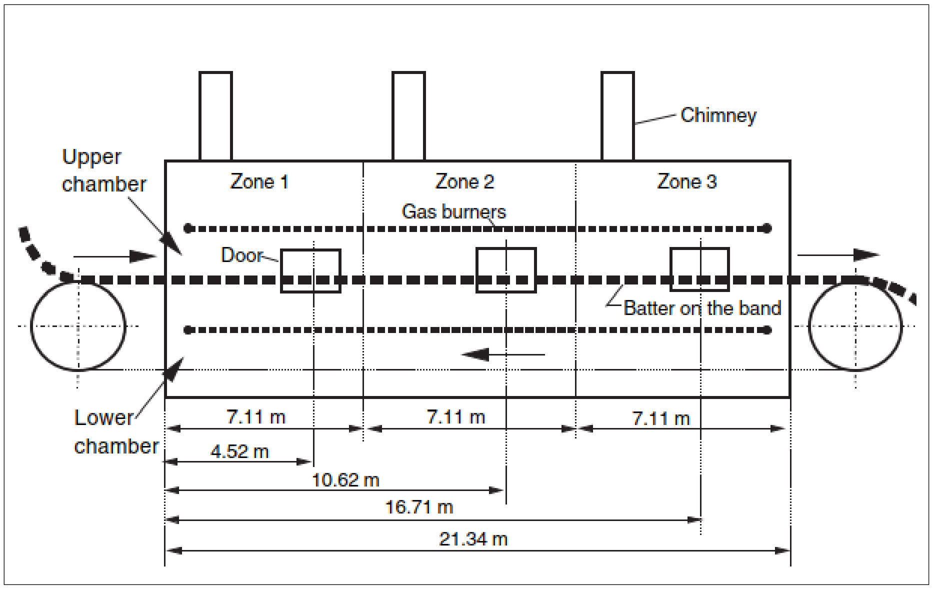


Figure 21: Zones in gas fired oven

All these zones involve temperature gradients, which are measured by the means of electrical thermo-elements or electrical resistance thermometers. By the means of an electrical output signal, the temperature of the oven can be controlled. For a temperature control of around 20K, a normal two point control system is advisable, however, for greater magnitudes, a three point control system is required. (Cauvain, 2015)

Thermoelectric control systems can be specifically designed for thermocouples, wherein multiple thermocouples can be connected to a single instrument (the oven), to monitor several temperature areas.

Few important considerations for control of the baking process are considered during the HAZOP Studies for the equipment. They are:

1) Sufficient convection (natural/forced)
2) Optimized air:gas mixture
3) Good Lateral heat control
4) Adequate spacing and clearance
5) Preventing entry of cold air into the oven
6) Humidity Control

Humidity for the oven is an important baking condition and is a parameter which directly influences the quality of bread produced. Generally, the humidity inside the oven is maintained at a constant value, expressed in terms of % Relative Humidity.

The humidity is influenced by three main factors: (Carson, 2019)

Oven Load influences the humidity inside the oven, as the higher quantity of baking capacity implies higher humidity, and thus more control.

Temperature of the oven wall affects the evaporation rate of water

Saturation level and steam quantity play a direct role in determining the humidity

The humidity is controlled using a humidity sensor, which measures the absolute moisture content for both, the heating and cooling cycle. The output is displayed as the humidity mass ratio (kg water/kg dry air) with respect to time. The output can also have the units of lb water/lb dry air, depending upon the units of measurement. However, this does not have any bearing on the ratio and would give the same output irrespective of the system used.

The use of a humidity control sensor for oven renders the following result:

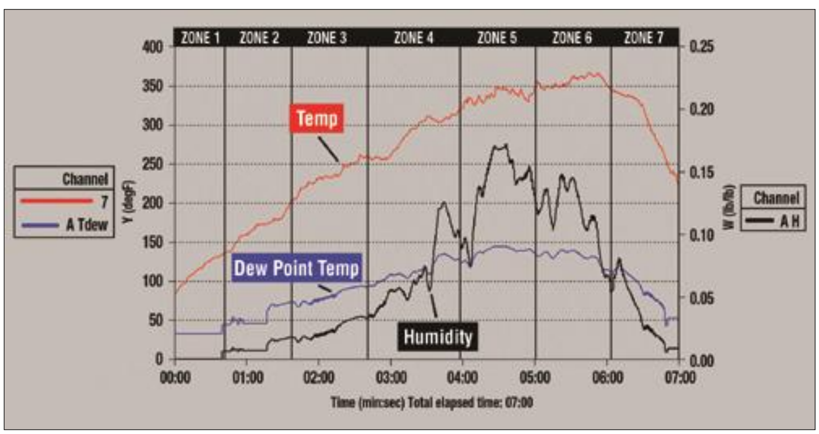


Figure 22: Humidity control output (Reading Thermal, 2019)

Other methods to maintain the humidity level is to maintain the water level for the steam inside the oven, by using a level indicator. The mechanical method to control the fluctuations in humidity is to use variable-speed fans and dampeners. An ideal control strategy would be to thus, employ a combination of both the dampeners and a humidity controller to minimize the fluctuations.

8.2. Fermentation Process Control

A closed loop control system is applied for dough fermentation based on image fermentation as put forth by Yousefi-Darani et al. (Yousefi-Darani, Paquet-Durand, Zettel, & Hitzmann, 2018)

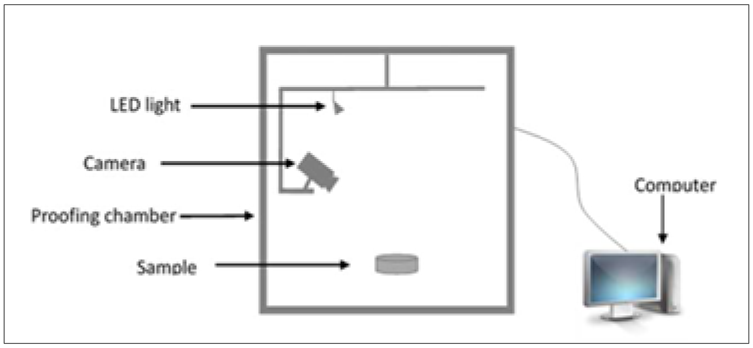


Figure 23: Monitoring strategy employed

This was the standard monitoring strategy employed by Yousefi-Darani et al. Based on this, the process control system was designed. A closed-loop or feedback system controller was chosen with a motive of disturbance rejection or set point tracking. A PID Controller is used and for simplicity, a SISO (Single input Single Output) controller was implemented. A MIMO (Multiple Input Multiple Output) controller can also be employed.

The design of the PID Controller is based on the standard laws of Process Control, with the control action being implemented according to the equation:

$$u(t) = k_c * \left[e(t) + \frac{1}{\tau_i}\int_0^t e(t)dt + \tau_D \frac{de(t)}{dt}\right]$$

Where, e(t)= SP(t)-Vm(t)

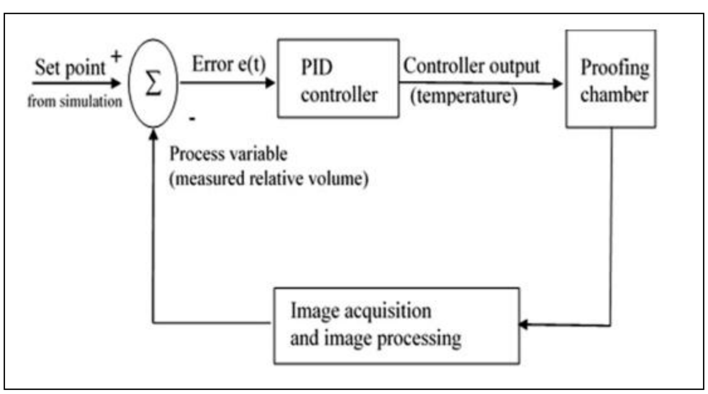
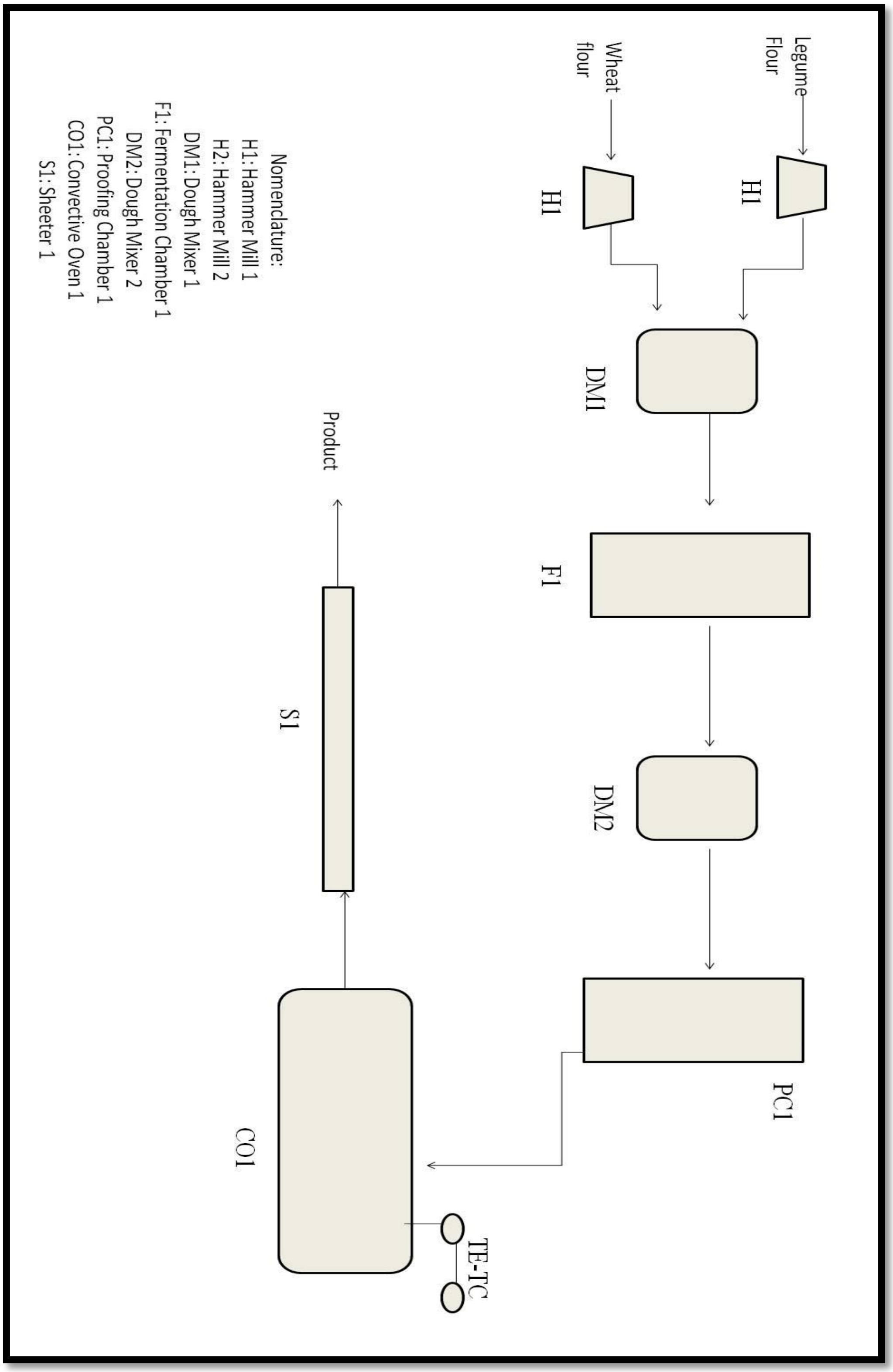


Figure 24: Closed loop PID controller for fermentation

Thus, in the PID Controller, The Set Point can be varied as per need, with the feedback through the image acquisition and processing (and other digital methods). In the methodology mentioned above, the controlled variable was the temperature and the process variable was the measured relative volume. However, these variables can be modified as per the parameter to be monitored. Over and above, in case of multiple variables, the controller can be designed accordingly.

9. __Process Flow Diagram__



10. Plant Layout

The plant layout for the Manufacture of 'Fermented Wheat Bread with Legume Flour' was conceptualized as follows:

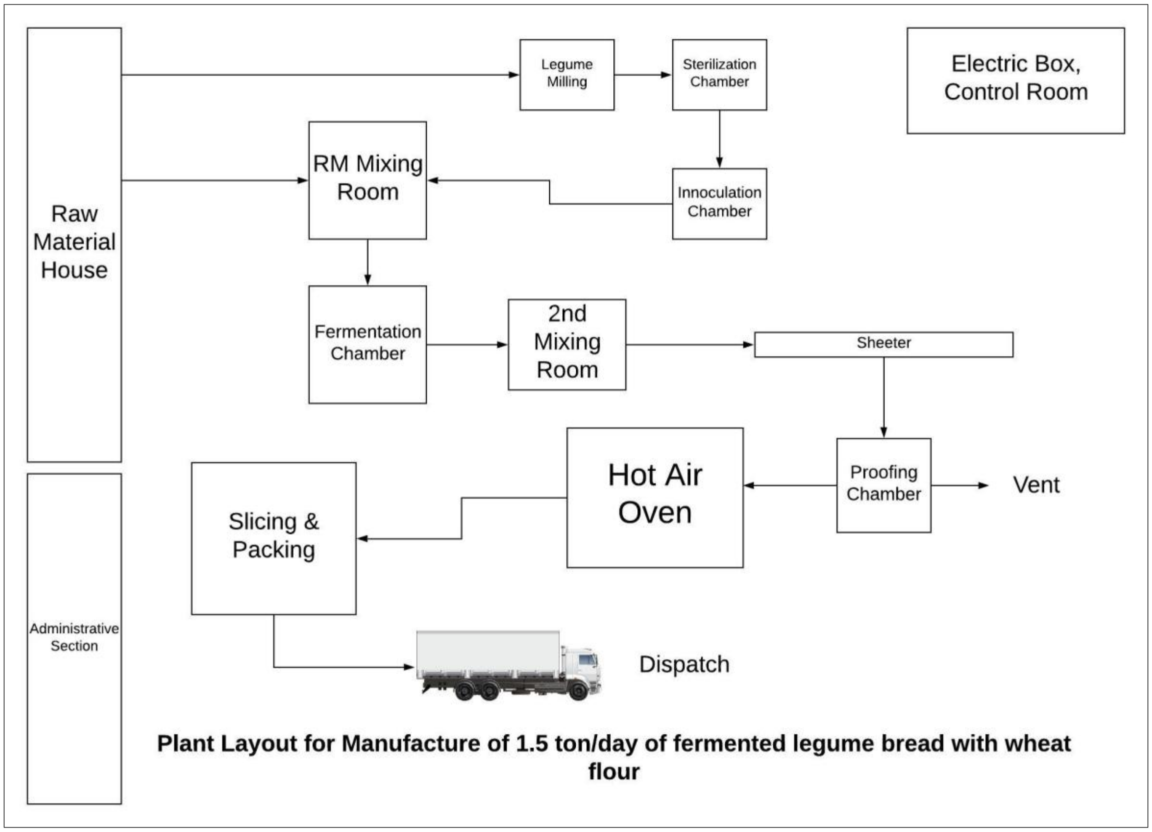


Figure 25: Plant layout for manufacture of 1.5 tons/day of fermented legume bread with wheat flour

The sub location of each of the subsections was carefully chosen after taking into consideration after close scrutiny as follows:

1. The Raw Material House was built closer to the administrative section, for facilitating faster loading of Raw Material from the supplier after completing the initial paperwork and payment formalities.
2. The Raw Material house would then further be subdivided into two major sections, the first hosting the wheat flour and the other hosting the legume. As the percentage of legume in the wheat bread is lower, the area allotted to that would be correspondingly lower.

3. The legume obtained would first be passed through a separate section, undergoing milling operations and then sterilized. On the other hand, the wheat flour would be directly transported to the mixing chamber.
4. The first mixing chamber would have a mixing drum (of appropriate size, based on the sizing above), wherein the wheat flour and legume flour would be homogenized, which would be further passed on to the fermentation chamber.
5. The process conditions for fermentation chamber would be decided through a design protocol. Fermentation process requires sensitive conditions, and thus, they are kept at a specialized location (between the two mixing rooms).
6. Post fermentation, the batch would be taken to a mixing room, with another mixing drum (preferably of the similar size of the first mixer). For simplicity of construction, the two mixing rooms are kept of the same dimensions.
7. The sheeter would require additional space, for it will have a series of conveyer belts, upon which the sheeting would be carried out. The sheeter, is thus to be allotted higher space.
8. The proofing chamber is comparatively smaller; however, the height of the proofing chamber needs to be kept high with a sufficient amount of clearance. A vent is attached to facilitate the escape of flue gases (other option is to install a carbon capture unit, however, it will add to the manufacturing costs).
9. The last major unit of the plant is the Oven section. A hot air oven of proper sizing is kept, with sufficient space for the bread to cool post baking. This is done by installing cooling racks (other option is to use continuous conveyer belts or spirals, however, it will add to the project costs.)
10. Finishing of the bread is done, first by slicing the bread into loaves and then packaging it, before the dispatch. Similarly, the finishing section is kept closer to the administrative section to expedite the paperwork and other formalities.
11. The control room is located further from the plant operations along with the electric meter box. The electricity is supplied using underground wires, rather than overhead wires. The process parameters are controlled using standard I&PC guidelines.
12. The plant layout is designed, keeping in mind the idea of growth and scale-up in future.

11. Working Schedule

The Bread manufacturing schedule would be worked out based on certain factors,

The plant has been designed to work at a capacity of 1500 kg/day of bread (weight by weight). This capacity is ideal for a medium sized plant, which can thus be easily downsized or scaled up based on the sales and turnover, after the initial year. The production can be done, in either of the two ways.

1. The first method would be to start the manufacturing at almost the full working capacity and then try to meet the sales through effective marketing techniques and effective supply chain methods.
2. The second method would be to estimate a demand for the product, and then manufacture the product accordingly. Market prediction can be done using practical methods such as market survey.

The working schedule can be divided into shifts of 5 hours each or a shift of 10 hours operation, with an aim to produce, atleast 150 kg/hr of bread. The factory workers can thus be scheduled for the same, with a working time of 300 days/year, with the net capacity, thus being 45 tons/year.

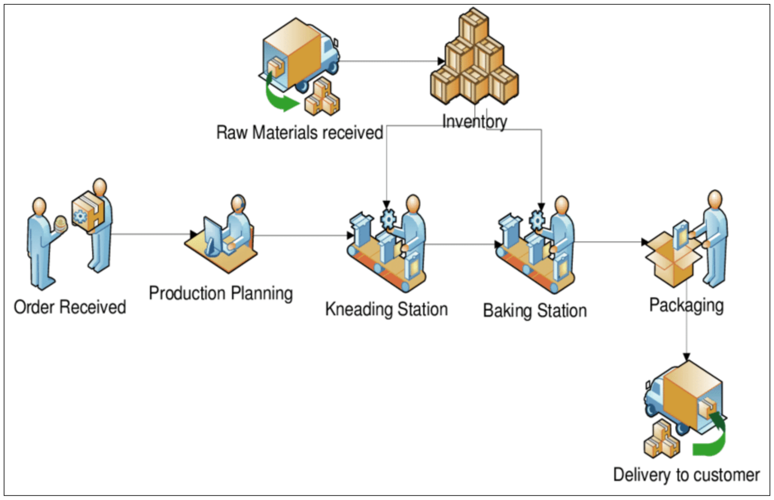


Figure 26: Schematic of working schedule

The schedule of operation would thus be fixed, with separate departments working on the separate operations in the plant. The administrative section, will, thus have the following responsibilities like stock checking and inventory replenishment, sales and marketing, production planning, packaging, delivery, supply chain, procurement etc.

12. Safety, Health and Environment

12.1. Safety

It is imperative to ensure proper safety for all equipments in the plant, especially near the fermentation chamber and the hot air oven (these being the most critical parts of operation).

- The hot air oven is subjected to considerably higher temperatures followed by an operation of natural or forced cooling. This area is prone to higher risk of explosion or fire as compared to the other parts of the plant. It must be ensured that proper timely checks of all temperature control devices is done and is kept within limit. Moreover, the electric wires must be properly insulated and grounded.
- Although the plant mainly deals with solid state conditions, leakage at any possible junctures must be minimized or even eliminated. The yeast addition during the mixing process or the water addition for wetting the dough must be done through proper channels and must be well monitored.
- The dough mixer and the hammer mill involve extensive mechanical operations. The chance of a malfunction in either of the two equipments can cause improper mixing and might affect the working of the fermentation chamber, and cause problems during the baking operation.
- Proper maintenance of wiring and equipments and proper enclosure of high voltage equipments is necessary to avoid hazards. There might be a case of short-circuit leading to fire, hampering the safety of all the personnel onsite.

12.2. Health

- All the working operators should be well-versed with the process data sheet of each equipment and the MSDS of all the involved chemicals.
- The workers at the Proofing chamber should be well equipped with respiratory protections such as masks and also wear safety goggles due to exposure to flue gases expelled during the proofing.
- Proper lab coats and safety wear should be worn at all stages by every working personnel, along with gloves, while handling material (yeast, etc).

- Shutdown procedure must be clearly conveyed to all workers and must be made alert of the health hazards they are exposed to.
- A full working capacity ambulance must be kept on site at all times, with the plant being at proximity to a working hospital.
- Guards must be kept alert during periods of shutdown or halt.

12.3. Environment

- All cables and pipes must be monitored carefully to avoid leakages and material loss (water, air).
- The flue gases emerging from the plant at various stages must be vented out. Moreover, a flue gas treatment unit could be set-up to treat the gases (although the gases are not hazardous in this case)
- Ensure that the plastic used for packaging is Food-grade and FDI certified. Moreover, the plastic is recyclable. During the packaging, ensure that all the unused plastic and its debris are recycled.
- Although the amount of waste-water is negligible, collaborate with an adjoining industry to treat the water at their waste-water treatment plan.

13. ***Economic Analysis***

Reference: (S.M. & V.V., 2016) and (Karl & Mutaria, 2014)

Equipment Cost

Based on the process, the relevant equipment cost was procured as follows:

Equipment	Cost (Rs)
Hammer Mill	17500
Sterilization Chamber	200000
Innoculation Chamber	31000
Incubator	70000
Hot Air Oven	17000
Grinding	225000
Dough Mixer	12000
Proving Chamber	45000
Sheeter	198000
Hot Air Oven	17000
Bread Slicer	56000
Equipment Cost	888500

Apart from the major processing equipments, excess investment is required in packaging machine (which is integral for bread manufacturing) and minor cost for installation (10% of equipment cost)

Equipment	Cost (Rs)
Equipment Cost	888500
Installation	208850
Packaging	1200000
Total	2297350

SLD (Straight Line Depreciation) is assumed at 10%.

Depreciation= 2.0885 Lacs/annum

Utilities Cost

For the bread manufacturing cost, an estimated of 20 hp is required. Cost of electricity generation is 5 Rs/kwh.

Utilities	Value	Unit
Requirement	20	hp
Requirement	14.914	KWh
Cost per kwh	5	Rs
Hrs/day	15	hrs/day
Cost per day	1118.55	Rs/day
Cost per year	408270.75	per year
Factor	1.2	excess
Total	489924.9	Rs

Land and Building

Required Plant Area is 1000 m2 and Building area is 700 m2. The cost of land, based on Rural areas is 10000 Rs/m2.

Entity	Cost (Rs)
Land cost per m2	10000
Total Land Cost	10000000
Building Cost	2000000
Insurance	100000
Misc	500000
Total	12600000

Component Cost

The important components are considered as mentioned in the book, 'Chemical Project Economics' by Mokashi and Mahajani:

Entity	Cost (Rs)	% Cost
Instrumentation	200000	2
Piping	300000	3
Electricals	200000	2
Maintainence & Services	500000	5
Engineering Services	800000	8
Construction Labor	500000	5
Contractor	200000	2
Contingencies	1000000	10
Total	3700000	

Raw Materials

The major Raw material prices were procured through competitive sources as follows:

Plant is operational for 300 days, with production of 1500 kg/day.

Raw Material	Cost (per day)	Cost per annum (Per year)
Black Lentil	12825	3847500
Wheat	15075	4522500
Xanthan Gum	9000	2700000
Yeast	2000	600000
Sugar	500	150000
Salt	500	150000
Improvisation	1000	300000
Total	40900	12270000

Project Cost

Net Project Cost is obtained as follows:

Entity	Cost (Rs)	Cost (in lacs)
Equipment	2297350	23
Land	12600000	126
Components	3700000	37
Miscellaneous	1859735	18.6

Total	20457085	205

Variable Cost

The labor is considered as: 20 laborers with an average pay of 10,000 Rs/month with 1 month bonus.

Overheads are considered as 10% of variable cost

Entity	Cost (Rs)	Cost(in lacs)
Raw Materials	12270000	123
Utilities	489924.9	4.9
Labor	2600000	26
Overheads	1535992	15.4
Total	16895917	169

Estimation of Working Capital

The working capital is estimated for a total of 30 days (stock inventory), accounting for 10% of annual production (out of 300 days).

Entity	Cost (Rs)	Cost (in lacs)
Raw Materials	1227000	12.3
Maintenance	1200000	12
Fixed Expenses	122700	1.23
Total	2549700	25.5

Estimation of Loan Interest

It is assumed that the breakup for the financing is considered as follows:

75% of total cost as Loan from Bank and the rest 25% of the cost through other sources.

The loan repayment has been taken from a bank with the nominal interest rate set at 10%, with repayment time of 10 years and borrowed with a Moratorium period of 2 years.

Equal installment is calculated as follows:

$$E = \frac{P*r*(1+r)^n}{(1+r)^n-1}$$

Where P=0.75*Total Cost = 280 lacs

Thus,

$$E = \frac{280*0.1*1.1^8}{1.1^8-1}$$

E = 52.5 lacs/year

Year	Principal	Interest Payable	Principal	Principal Left	Total payable
0	280.1475179	-	-	-	-
1	280.1475179	28.01475179	0	280.1475179	28.01475179
2	280.1475179	28.01475179	0	280.1475179	28.01475179
3	280.1475179	28.01475179	24.49722448	255.6502934	52.51197627
4	255.6502934	25.56502934	26.94694693	228.7033465	52.51197627
5	228.7033465	22.87033465	29.64164162	199.0617049	52.51197627
6	199.0617049	19.90617049	32.60580578	166.4558991	52.51197627
7	166.4558991	16.64558991	35.86638636	130.5895127	52.51197627
8	130.5895127	13.05895127	39.453025	91.13648775	52.51197627
9	91.13648775	9.113648775	43.3983275	47.73816025	52.51197627
10	47.73816025	4.773816025	47.73816025	2.34479E-13	52.51197627

Breakeven analysis

Component	Cost (in lacs)
Variable	168.9592
Fixed	61.37126

For nutrition bread, the competitive selling price is 35 Rs /piece.

Also, quantity of one packet is 0.4 kg.

Thus, in 1 kg of product, there are 2.5 pieces.

Thus, Selling Price per Kg = 35*2.5= 87.5 Rs

Breakeven Quantity, $Q = \frac{F+V}{SP}$

Calculating, Q=263235 kg/annum

Thus, breakeven Capacity is:

$X = \frac{263235}{450000} = 0.585$

Thus, for breakeven capacity, the plant can be run at 58.5% of its full capacity.

14. Site Selection

The site selection is an important strategic level decision for any organization as a large investment is made on the several areas such as land, machinery, building etc. Hence, an improper decision about the location of the plant can lead to waste of all the investments and thus, several factors need to be considered before the selection of the site.

Before a location for a plant is selected, long range forecasts should be made anticipating future needs of the company. The plant location should be based on the company's expansion plan and policy, diversification plan for the products, changing market conditions, the changing sources of raw materials and many other factors that influence the choice of the location decision. The purpose of the location study is to find an optimum location one that will result in the greatest advantage to the organization.

14.1. Factors affecting Site Selection

14.1.1. Availability of Raw Materials

The top three states in the production of black lentils in India are Madhya Pradesh (420,000 tonnes), Uttar Pradesh (240,000 tonnes) and Bihar (190,000 tonnes) in the year 2014-15 according to the ministry of agriculture in India. Due to the highest production of lentils in Madhya Pradesh, setting up a plant there would reduce the raw material costs the most**. This in turn would increase the rate of return of the plant and hence the weightage assigned to this factor is 10.**

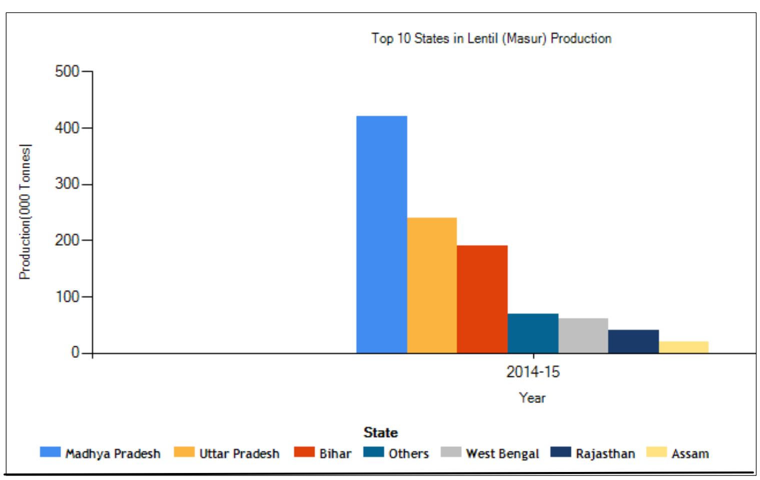


Figure 27: Plot of production per thousand tons of black lentils in India (2014-15)

14.1.2. ***Availability of Water and Power***

Power and water are very important utilities in the project. In order for a smooth operation of the plant continuous supply of power is necessary. Also water is required for dough making procedure. Hence a **weightage factor of 10 is assigned for power and water.**

14.1.3. ***Land***

Land is an important aspect to setting up of project, especially it being developed and suitable for industrial use. This is generally taken care of by setting up a project in Industrial Areas of various districts. **A weightage factor of 8 is assigned for land.**

14.1.4. ***Climatic Conditions***

Climatic conditions include maximum and minimum temperatures prevailing in the area, wind velocity and humidity. Climate is not the most important factor to be considered in case of a product like bread as artificial industry conditions can be fabricated and also because the range of temperatures in India do not amend much. **Hence the weightage factor assigned for climatic conditions is 7.**

14.1.5. ***Dispersal of Industries***

Dispersal of industries is essential for uniform economic growth of the country. Industrially backward areas need to be explored as project sites so as to increase prosperity in those areas. **A weightage factor of 9 is assigned for dispersal of industries.**

14.1.6. ***Appropriate use of resources***

India is abundant with natural resources which are widespread in this country; hence it becomes necessary to place projects so as to appropriately use resources and sources of energy as locally available. **A weightage factor of 8 is assigned for appropriate use of resources.**

14.1.7. ***National Security***

Industries must not be located in places of high tension such as disputed and hostile borders. Industries such as nuclear reactors, refineries must be located with considerable weightage of this factor. But Legume infused bread not being a product of strategic importance, **the weightage assigned to this factor is 7.**

14.1.8. Environmental aspects

Environmental aspects depend on the standards of compliance that a project decides to follow. ISO 14000 compliance leads to greater expense than a compliance with the local standards. **The weightage factor assigned to this factor is 10.**

14.1.9. Housing, Labor and Human Resource Convenience

The project is designed to be a batch plant. It will have an operating period of 10 hours in the day. Hence, labour would be required for to handle the batch process. Further, if the project is placed in regions of backward development, other convenience measures such as transport and housing. **The weightage factor assigned to this is 8.**

14.1.10. Transport Facilities

Transport facilities especially roads and railways are very important to any project site. Transport is required for humans, equipment, raw materials and products in and out of the project site. **The weightage factor assigned to this is 10.**

14.1.11. Communication

Communication in the form of internet, telephone and mobile networks are of utmost importance in this 21st century. Many parts of the country still lack these basic communication facilities**. It is hence necessary to assign a weightage of 10 to this factor.**

Table 20: Weightage factor table for different sites

Criteria	Weightage	Site X (Uttar Pradesh)	Site Y (Madhya Pradesh)	Site Z (Bihar)
Availability of Raw materials	10	9	10	8
Availability of Water and Power	10	9	9	7
Land	8	8	7	8
Climatic Conditions	7	7	7	7
Dispersals of	9	7	8	6

Industries				
Appropriate use of resources	8	7	8	7
National Security	7	7	7	7
Environmental Aspects	10	7	8	6
Housing, Labour and Human resource convenience	8	8	7	8
Transport Facilities	10	8	9	8
Communication	10	9	9	8
	97	**86**	**89**	**80**

As we can deduce from the above table that Madhya Pradesh is perhaps the appropriate site for our plant. Let us now calculate the rate of return for each plant.

14.2. Locational Economics

The various costs which decide locational economy are those of land, building, equipment, labour, material, etc. Other factors like community attitude, community facilities and housing facilities will also influence the selection of best location. Economic analysis is carried out to decide as to which locate best location.

For 5 years,

Table 21: Data to calculate the rate of return for each site

	Site X (In Rupees)	Site Y (In Rupees)	Site Z (In Rupees)
Total capital investment	8,96,500	8,96,500	8,96,500
Total expected sales	10,00,00,00	11,00,00,000	9,00,00,000
Distribution expenses	0	17,50,000	16,00,000
Raw materials expenses	15,00,000	5,53,99,500	5,87,74,500
Water and power supply	5,67,49,500	6,00,000	7,50,000

expenses Wages and Salaries Other expenses Community attitude Employee housing facilities	7,00,000 1,20,00,000 9,00,000 Indifferent Poor	 1,30,00,000 10,00,000 Want Business Excellent	 1,25,00,000 11,00,000 Indifferent Good

Thus,

Total expenses	Site X (In Rupees)	Site Y (In Rupees)	Site Z (In Rupees)
Addition of points 3,4,5,6,7	7,18,49,500	7,17,49,500	7,47,24,500

$$\text{Rate of return (RoR)\%} = \frac{\text{Total sales} - \text{Total expenses}}{\text{Total Investment}} \times 100$$

$$\text{RoR for Site X} = \frac{10{,}00{,}00{,}000 - 7{,}18{,}49{,}500}{8{,}96{,}500 + 7{,}18{,}49{,}500} \times 100 = 38.69\%$$

$$\text{RoR for Site Y} = \frac{11{,}00{,}00{,}000 - 7{,}17{,}49{,}500}{8{,}96{,}500 + 7{,}17{,}49{,}500} \times 100 = 52.65\%$$

$$\text{RoR for Site Z} = \frac{9{,}00{,}00{,}000 - 7{,}47{,}24{,}500}{8{,}96{,}500 + 7{,}47{,}24{,}500} \times 100 = 20.2\%$$

Hence, Madhya Pradesh can be selected because of high rate of return.

15. Conclusion and Future Scope

With the project, the technicalities involved in the development of a functional wheat bread using legume flour were studied. In addition, the intricacies of setting up a plant, by scaling it up from the laboratory to plant capacity were studied and reported.

The economics involved in setting up of the plant is instrumental in implying the humungous costs which are involved in setting up of a plant and also the miscellaneous costs (apart from the raw material costs) were noted and calculated.

The development of a functional wheat bread using legume flour is of great significance in the future. It is a layman's observation that the world is moving towards a healthier diet in order to improve their health and as a way of tackling all of their health problems. As far as the choice of the legumes in the project is concerned, all the three legumes are rich in its nutritional properties, which would contribute to the bread being even healthier, than a normal wheat bread.

Although there would be a number of challenges involved in bringing these products into the market, the acceptability of this product would be high; owing to its nutritional value and also competitive price (The price was found to be competitive through the economic analysis done).

The added advantage of setting up a plant of bread as compared to other products is that, the number of equipments involved is on the lower side, and also less complicated. The number of byproducts and co products produced in the process are zero, with no problem of excess waste. Moreover, the environmental hazards are negligible as compared to other specialty products, thereby saving costs on establishing an effluent treatment plant.

The breakeven capacity was found to be 58% of the installed capacity, indicating that the plant capacity can be further increased to obtain a profitable venture.

In totality, the bread manufacturing unit can serve to be extremely profitable if set up with the right methodology and investing heavily in the R&D centre, in order to focus on developing the taste and appearance of the product.

16. Annexures

16.1. Market Analysis of Types of Breads available

Table 22: Market analysis of types of bread

Brand	Quantity	Price	Ingredients	Proteins per 100g (gm)	Carbs per 100g (gm)	Energy per 100g (Kcal)
Bakers choice	400gm	32 Rs	Maida, aata edible vegetable oil,yeast, iodized salt,grain sugar	7.7	17.2	252
Wibbsbrowny	400gm	35 Rs	Whole wheat flour, water, wheat flour, wheat gluten, soyaflour,yeast, iodized salt,vegetable oil,	12.7	48	248.4
Britannia whole wheat	400gm	35 Rs		8	50	250
Mahawibbs white bread	400gm	25 Rs		12.4	49.6	254.2
Britannia wheata rich	400gm	25 Rs	Refined wheat flour, sugar,yeast,iodisedsalt,edible vegetable oil,soya flour ,water	7	51	250

16.2. Market Analysis of Types of Flours available

Table 23: Market Analysis of Types of Flours available

Brand	Quantity	Price (In Rs)	Ingredients	Proteins per 100g (gm)	Carbs per 100g (gm)	Energy per 100g (Kcal)
Kuttuaata	500gm	244	100% buckwheat protein	13.15	68.08	361.37
Godham Multigrain aata	1000gm	75	Sharbati whole wheat 60%, 40% corn,jawar,bajra,flax ,seed,ragi,gram,soyabean,bran barley	13.09	75.19	379.67
Godham diet aata	1000gm	105		10.2	74.7	390
Godhammultiwheataaata	2000gm	-			75.57	375
Diabetic ++		-		12.43	73.9	366.8

16.3. Market Price of Selected Legumes

Table 24: Market Price of Selected Legumes

Quantity	Soybean	Adzuki Beans	White peas	Lentils
1 kg	Rs 36/-	Rs 230/-	Rs 60/-	Rs 60/-
10 kg	Rs 350/-	Rs 2200/-	Rs 550/-	Rs 550/-
100 kg	Rs 3400/-	Rs 21000/-	Rs 5400/-	Rs 5400/-

16.4. Python Code (Temperature Profile)

(Compiled using Jupyter notebook)

```
import scipy
import scipy.integrate
import matplotlib.pyplot as plt
%matplotlib inline
t=scipy.linspace(0,60*60,100)
T0=20+273.16
h=3
A=2*scipy.pi*0.07*0.2
T_inf=473
eps=0.9
rho=530
cp=1000
sigma=5.67*10**(-8)
V=scipy.pi*0.07**2*0.2
def dTbydt(T,t):
dTbydt=(-h*A*(T-T_inf)-eps*sigma*A*(T**4-T_inf**4))/(rho*cp*V)
return dTbydt
sol=scipy.integrate.odeint(dTbydt,T0,t)
plt.plot(t/60,sol-273.16)
plt.xlabel("Time (minutes)")
plt.ylabel("Surface Temperature of Bread (in celsius)")
```

22. *plt.title('Temperature profile of bread')*
23. *coeff=scipy.polyfit(t,sol,3)*
24. *T_fit=coeff[0]*t**3+coeff[1]*t**2+coeff[2]*t+coeff[3]*
25. *plt.plot(t,sol,"b")*
26. *plt.plot(t,T_fit,"r")*

16.5. Python Code (Water Loss)

Compiled using Jupyter notebook

1. *Mair=28.84*
2. *Mwater=18*
3. *v=28.86*10**-6*
4. *alpha=1.17*10**-7*
5. *psa=1*
6. *RH=10*
7. *D=1e-4*
8. *psat=1*10**5*
9. *Sc=v/D*
10. *Sc*
11. *Pr=v/alpha*
12. *Pr*
13. *kgo=h*Mwater/Mair/psa/cp/((Sc/Pr)**(2/3))*
14. *kg=kgo*7.83*10**-3*
15. *kg*
16. *def dWbydt(W,t):*
17. *dWbydt=-1*kg*psat*(((100*W/(np.exp(-1*0.0056*(coeff[0]*t**3+coeff[1]*t**2+coeff[2]*t+coeff[3])+5.5)))**(-1/0.38)+1)**-1*((coeff[0]*t**3+coeff[1]*t**2+coeff[2]*t+coeff[3])**2)-(RH/100)*T_inf**2)/D/rho*
18. *return dWbydt*
19. *aw=((100*W/(np.exp(-1*0.0056*(coeff[0]*t**3+coeff[1]*t**2+coeff[2]*t+coeff[3])+5.5)))**(-1/0.38)+1)**-1*
20. *aw*

21. sol_w=scipy.integrate.odeint(dWbydt,W0,t)

*22. loss=(W0-sol_w)/W0*100*

23. plt.xlabel("Time (minutes)")

24. plt.ylabel("Loss %")

25. plt.title('Loss of moisture vs time')

26. plt.plot(t/60,loss)

16.6. Phytic acid Test

Test A

1. Weigh a finely ground sample (40 mesh) estimated to contain 5 to 30 mg. phytate P into a 125-ml. Erlenmeyer flask.
2. Extract with 50 ml 3% TCA for 30 min. with mechanical shaking or 45 min. with occasional swirling by hand.
3. Centrifuge the suspension and transfer a 10-ml aliquot of the supernatant into a 40-ml conical centrifuge tube.
4. Add 4 ml $FeCl_3$ solution (made to contain 2mg. ferric iron per ml. in 3% TCA) to the aliquot by blowing rapidly from the pipet.
5. Heat the tube and contents in a boiling-water bath for 45min. If the supernatant is not clear after 30 min. add 1 or 2 drops of 3% sodium sulfate in 3% TCA and continue heating.
6. Centrifuge (10 to 15 min) and carefully decant clear supernatant.
7. Wash precipitate twice by dispersing well in 20 to 25 ml. 3% TCA, heating in boiling-water bath 5 to 10 min and centrifuging.
8. Repeat wash once with water.
9. Disperse the precipitate in a few ml. water and heat in boiling-water bath for 30 min,
10. Bringing volume to approximately 30 ml. with water and heating in boiling water bath for 30 min.
11. Filter hot (quantitatively) through a moderately retentive paper (S & S 597, Whatman No.2)
12. Wash precipitate with 60 to 70 ml hot water and discard filtrate. If phosphorous determination is desired, it may be made on this filtrate.

13. Dissolve the precipitate from the paper with 40ml hpt 3.2N HNO_3 into a 100-l volumetric flask.
14. Wash paper with several portions of water, collecting the washing in the same flask.
15. Cool flask and contents to room temperature and dilute to volume with water.
16. Transfer a 5-ml aliquot to another 100-ml volumetric flask and dilute to approximately 70ml.
17. Add 20 ml of 1.5M KSCN, dilute to volume, and read color immediately (within 1 min) at 480nm.
18. Run a reagent blank with each set of samples.
19. Calculate iron content from $Fe(NO_3)_3$ standard run at the same time or read from a previously prepared standard curve.
20. Calculate the phytate phosphorous from the iron results assuming a 4:6 iron:phosphorus molecular ratio. **Invalid source specified.**

Test 2

1. For the analysis of plant material the sample has to be extracted with **0 . 2** HCl.
2. Pipette 0.5 ml of this extract (3-30 pg**ml-1** phytate phosphorus) into a test tube fitted with a ground-glass stopper.
3. Add 1 ml of solution .
4. Cover the tube with the stopper and fix it with a clip.
5. Heat the tube in a boiling water bath for 30 min.
6. Take care for the first 5 min that the tubes remain well stopped. After cooling in ice water for 15 min allow to adjust to room temperature. **Invalid source specified.**

Once the tubes have reached room temperature, two alternative procedures may be followed:

Variant a: Mix the contents of the tube and centrifuge for 30 rnin at 3000 ***g.*** Transfer 1 ml of the supernatant to another test tube and add 1.5 ml of solution (iii). Measure the absorbance at 519 nm against distilled water.

Variant b: Do not centrifuge but add 2 ml of solution (iii) to the test tube after it has reached room temperature and mix the contents. The absorbance must be measured after a defined time ***(0.5-***1 min is recommended) because the bipyridine reacts with the iron phytate and therefore the colour changes with time.

The results obtained by the two alternative procedures are identical. Variant a is simpler to work with and has a slightly lower mean error, but variant b is much faster.

16.7. Cd-Ninhydrin Test

The mixture of Cd-ninhydrin reagent and the ethanolic extract of the sample was heated at 84 °C for 5 min. The absorbance of ninhydrin-amino acid complex solution was measured at 507 nm and FAA content was expressed as equivalent amount of leucine present in the sample. **Invalid source specified.**

Preparation of Standard Curve for Amino Acid content estimation:

1. Prepare 3% leucine w/v in water.
2. Continuous shaking by hand for 10-15 min
3. Concentration was varied from 0 to 1 with an interval of 0.2 ml, and makeup volume till 1ml with water
4. Add 2ml of Cd-Ninhydrin reagent in each of the sample preparation
5. Heat the solution in water bath at 80 ^{o}C for 10 min.
6. Analyze the sample in the spectrophotometer at the wavelength of 507mm.

Experimental Method to calculate the Amino Acid Content was carried out as follows:

A sample was prepared by-

1. 5 g of whole wheat flour was mixed with 29 mL of absolute ethanol and was centrifuged for 15 minutes at an RPM of 8000.
2. After complete extraction of amino acids into the ethanol, supernatent was removed and 1 mL was diluted to 100 mL.
3. 1 mL of diluted sample was taken for the ninhydrin test and was analysed spectrophotometrically.

16.8. Fermentation of Legume Flour

- According to the method described by Xiao et al. (2015), solid state fermentation was carried out for the fermentation of the legume flour. Initially, the legume is ground to

1mm mesh using a hammer mill to convert it into legume flour and further sterilized at $121^{o}C$ for 25 minutes.

- This step is followed by cooling to room temperature which is about $25\pm2^{o}C$. The sterilized legume flour was then inoculated with desired levels of active dry yeast extract (S. cerevisiae) with 4% sucrose for initiating growth in the fermentation process. Distilled water was sprayed in the inoculation chamber to maintain 20% moisture content.
- After inoculation of the yeast extract, the sample is flattened out to a 5mm sheet on an aluminum tray covered with muslin cloth and is incubated at $30\pm1^{o}C$ at 85% humidity. Samples were analyzed every 12 hours to measure the decrement in the anti-nutritional properties and the increase in the free amino acid content.
- After incubation, the yeast is then made inactive by placing the sample in a hot air oven at $T=52^{o}C$ for another 12 hours. Further, it was ground in a home mixer and stored in a cool and dry place.

16.9. ***Baking***

- Prepare the sugar-salt solution and yeast solution according to AACC International method 10-10.03.
- Add the milled legume, yeast solution, sugar-salt solution, water, wheat flour and other binding agents to the mixer bowl.
- Mix till point of minimum mobility is reached. Transfer dough from bowl to table top, insert dough thermometer, and record temperature after 30–60 sec.
- Estimate absorption relative to an optimum concept by feeling dough consistency. Round dough by hand, keeping smooth skin on top side.
- Observe and record dough characteristics.
- Place seam side down in lightly greased fermentation bowl and place in fermentation cabinet.
- Remove the dough from the fermentation cabinet after roughly 90 minutes and then lay it into sheets using a sheeter.
- Return to the fermentation cabinet. To proof to desired height usually requires 33 ± 2 min. Record proof height and time.

- Oven temperature for 1-lb loaves and loaves from 100 g flour is 215° (419°F), and bake time is 24 min. For loaves from 10 g flour, oven temperature is 232° (450°F), and bake time is 13 min.

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