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Standardisation of Flour Testing in Alveograph NG

Prasun Das and Susanta Kumar Gauri

Abstract: Flour is the major ingredient for biscuit manufacturing. The selection of flour for a particular variety of biscuits is based on the performance of the Extensibility(E) and Resistance (R) properties, in general. However, the testing times of "E" and "R" led to an issue of 67% untested consignments of flour. In order to overcome these shortcomings, a new instrument, called Alveograph NG, was installed which can estimate Tenacity(P) and Extensibility(L) properties quickly and based on these values different types of flour should be discriminated. This study was undertaken to standardise the working norms of "P" and "L" properties of flour measured in the new instrument. Data collected on two types of flour showed that the tenacity(P) is the only significant discriminatory property of flour. In the event of this significant difference, the same data were subjected to ANOVA, using a two-way random effect model,which, however, yielded no useful result. Based on tenacity(P), operating rules for segregation of flour were developed allowing in a majority of cases a classification. Considering additionally Dry Gluten% as a further discriminating factor, the probability of successful classifications could be increased. There would be a significant improvement in cost with respect to enormous time saving for flour testing as well as selection of flour with high precision and accuracy. The entire methods of sampling, testing and decision making through Alveograph NG has become a routine practice in the organization.

1 Introduction

Packets of biscuits of different varieties are the end products of a reputed Biscuit manufacturing company in India. Flour is the major ingredient of biscuits. Estimation of chemical properties like gluten%, total ash%, acid insoluble ash%, alcoholic acidity%, wheat germ oil acidity% and sedimentation value of flour and ensuring their conformance to the standards satisfy the processing and quality requirements for different variety of biscuits.

Apart from these, the suitability of flour for a particular variety of biscuits is determined based on the performance of the extensibility(yeasted) and resistance (yeasted) properties. The estimates of the other characteristics like MC%, WAP% and granularity helps to decide about how much water to be added during mixing, once the flour is selected for preparation of a particular variety of biscuits.

The two special varieties of biscuits are "Cracker-A" and "Snack-B". The specifications on extensibility(yeasted) and resistance(yeasted) for these two varieties are as follows:

Table 1: Biscuit Specifications

	Cracker-A	**Snack-B**
Extensibility (E)	> 15.5	$16 - 20$
Resistance (R)	> 350	250 - 300

The high "R" value prevents tearing of sheet during sheet layering, whereas high "R" and moderate to high "E" help baking. As a result of it the biscuits achieve the desired thickness and taste. For all other variety of biscuits, general flour is required which is characterised by having resistance(yeasted) between 270-350 and extensibility(yeasted) between 12.5-15.5. The Extensometer is the strength measuring instrument which stretches the dough pieces and records the forces acting on these doughs during extension. The dough strength reflects the state of the flour dough through Extensibility (E) and Resistance (R) measurements as it goes into the processing. In this manner, the right type of flour is issued for production of a particular variety of biscuits.

2 Problem Background

Under the existing infrastructure, the estimation process for extensibility(E) and resistance(R) through Extensometer of a particular consignment of flour was taking 4.5 hours, on an average. So, in a day "E" and "R" could be tested for two consignments of flour only, whereas, an average of six (6) consignments of flour are being consumed everyday. This resulted in issuing an around 67% untested consignments of flour for biscuit production, which, in turn, could lead to many quality problems during processing. In order to overcome these shortcomings, a new instrument called Alveograph NG was installed in the laboratory of the Quality Assurance Department. This new instrument can estimate tenacity(P) and extensibility(L) properties of flour by 40 minutes. If a consignment of flour is suitable for production of a particular variety of biscuits, it is supposed to be determined easily based on these "P" and "L" values. Thus, it would be possible to assess all consignments of flour within a day prior to their release from stores for production. However, the specifications of "P" and "L" for different varieties of flour were not standardised for this purpose.

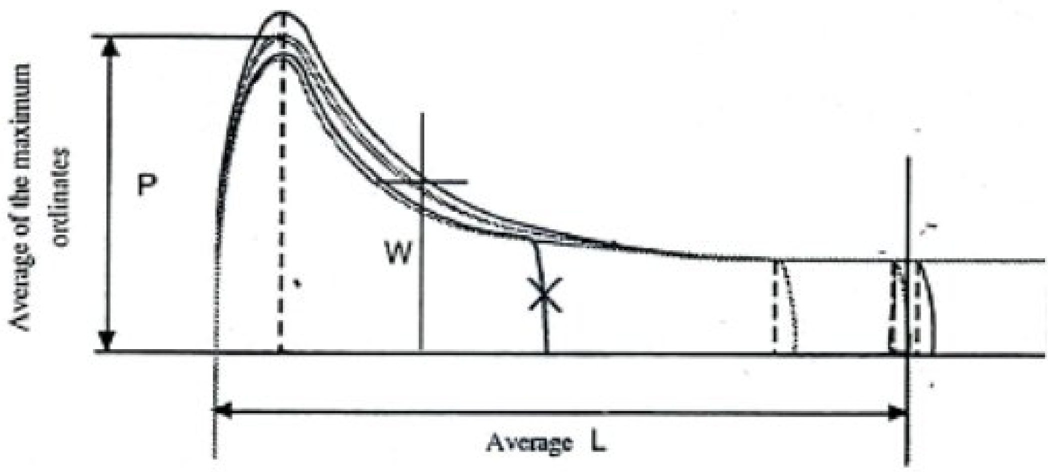
3 How an Alveograph NG Works

The method involves a biaxial extension of the dough sample (water+salt+flour) which, under air pressure becomes a bubble. This expansion method simulates the deformation of the dough sample under the influence of the biological or chemical origin gas production. The steps are as follows, in brief :

1. *Preparation of sample*

2. *Temperature and timer settings in Alveograph*
3. *Mixing process of (flour+salt+water)*
4. *Extraction, forming and relaxing the dough sample*
5. *Preparing for the test*
6. *Performing the tests for "P" and "L" parameters*

The results are measured from the five curves (as shown below) obtained on the manometer.



where

"P" : tenacity(maximum pressure required for the deformation of the sample)
"L" : extensibility (length of the curve)
"P/L": configuration ration of the curve
"W": baking strength (surface area of the curve)
"p" : pressure at bubble breaking point

It is reported in the instrument manual that under normal conditions, apparatus, laboratories and with operators being different, reproducibility can be estimated as C.V.%(P) = ±8%.

4 Preliminary Investigation

Discussions with the concerned technical personnel of the company revealed the fact that the numerical values of E and R in the earlier process of estimation could well be correlated with the L and P values respectively in the newly installed instrument. This explanation was accepted because of similarity of flour properties based on the definitions of these parameters.

Based on this discussion, different flour consignments were tested simultaneously both in extensometer as well as in alveograph. The corresponding values of (E,L) and (R,P) were obtained and subjected to correlation analysis through scatter plots. The analysis showed no association between these observations, which led to the conclusion that "P" and "L" can not be standardised for Cracker-A, Snack-B and the other general categories through modeling with respect to "R" and "E", respectively. So, it was decided to study the tenacity(P) and extensibility(L) characteristics of the flour independently and thereby standardise the working specifications for these two parameters in case of aforesaid categories of flour.

5 Objective

Consequently, a detailed study was undertaken with the following objectives :

a) To test whether any difference exists between the Cracker-A flour and Snack-B flour variety with respect to tenacity(P) and extensibility(L) properties of the flour.

b) In the event of any significant difference, to explore the nature of this difference and verify the capability of the estimation process under the possible uncertainties.

c) To evolve a suitable criteria for selection of flour for a specific variety and investigate the possibility of reducing the chance of misclassification, if possible.

6 Data Collection

At the outset, 2 bags of flour were randomly chosen from one consignment of Cracker-A variety. From each bag, 3 samples of flour each weighing 250 gms. were collected by each lab inspector. To carry out the entire experiment, 2 experienced lab inspectors were selected. Thus there were altogether (2x3x2)=12 sample observations, obtained through Alveograph NG, each for "P" and "L" respectively.

Similar exercise was also carried out for Snack-B variety of flour.

7 Analysis and Results

7.1 Summary Statistics

The collected data were summarised to find out the variety wise averages and standard deviations of the tenacity(P) and extensibility(L) properties. The results are displayed below.

Table 2: Summary of data on P and L

Characteristic	Flour : Cracker-A		Flour : Snack-B	
	Average	Std. Dev.	Average	Std. Dev.
"P"	85.97	8.11	65.83	4.34
"L"	55.09	4.28	55.10	6.45

7.2 Tests on differences in Averages and Variances

In order to detect whether there exists any significant differences in average level and variability around the average, the above summary findings were subjected to pair wise comparison of "P" and "L" for the two flour categories. The computational details are given in Annex A1. The results found are displayed below.

Table 3 : Pair-wise Comparisons of "P" and "L"

Parameters	With Respect To	
of interest	Average Level	Variance
"P"	Flours are different	Flours are different
"L"	Flours are same	Flours are same

It was thus observed that the tenacity(P) property of flour is the significant discriminatory factor for Cracker-A and Snack-B variety of biscuits.

7.3 Analysis of Variance

In order to obtain more inside into the sources of variability exhibited by the tenacity(P) property, the same data were subjected to two-way ANOVA as recommended in most statistics textbooks. The following 2-way random effect model was adopted for the analysis :

$$\begin{aligned} Y_{ijk} &= \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk} \\ &\quad i = 1, 2; j = 1, 2; k = 1, 2, 3 \end{aligned} \tag{1}$$

where

μ : overall average

α_i : effect of ith sample bag

β_j : effect of jth inspector

$(\alpha\beta)_{ij}$: sample and inspector interaction

ϵ_{ijk} : random error

Y_{ijk} : an individual observation on tenacity(P)

Table 4: ANOVA table for tenacity(P) - Snack-B

Source	D.F.	S.S.	M.S.	F-ratio
Sample	1	1.22	1.22	< 1
Inspector	1	82.69	82.69	< 1
Sample/Inspector	1	84.37	84.37	17.47*
Error	8	38.64	4.83	–
Total	11	206.92	–	–

Table 5: ANOVA table for tenacity(P) - Cracker-A

Source	D.F.	S.S.	M.S.	F-ratio
Sample	1	226.64	226.64	2.62
Inspector	1	295.72	295.72	3.41
Sample/Inspector	1	86.66	86.66	6.05*
Error	8	114.55	14.32	–
Total	11	723.57	–	–

Note:

1. * indicates significant source at 5% level.

2. The formulae for calculation of S.S. and expected M.S. are provided in Annex A2.

Accordingly the only statistically significant contribution to the variability of the observations is caused by the interaction of sample and inspector. This result makes intuitively no sense and, therefore, should be discarded.

The failure of ANOVA to yield a useful result should give reason to look at the underlying model (1), which basically assumes the random variable Y_{ijk} can be represented by the sum of the four (independent) random variables (effects) α_i, β_i, $(\alpha\beta)_{ij}$ and ϵ_{ijk}. From a more realistic point of view, there are almost no reasons, which could be forwarded backing this assumption. Therefore, using ANOVA may lead to useless or misleading results.

7.4 Interpretation of Results

1. Since no significant difference was found with respect to average and variability of the extensibility(L) property between Snack-B and Cracker-A variety of flour (see Tables 3 and 2) there appears no need to compute for an estimate of extensibility(L) from the curve on the manometer obtained through the alveograph test.

2. Significant difference was observed with respect to average and variability of the tenacity(P) property between Snack-B and Cracker-A variety of flour (see Tables 3 and 2). The average level and variability were both found statistically larger for Cracker-A variety of flour than that of Snack-B variety (see Annex A1). Therefore, it is worthwhile to use the estimated value of "P" alone for segregation of flour with respect to Cracker-A and Snack-B variety.

3. Thus, only the numerical results in Table 2 concerning the tenacity(P) property are used for judging the conformity with respect to the specifications for Snack-B and Cracker-A variety of flour. Backed by a normal probability plot. it is assumed that the tenacity property P follows the normal distribution. Replacing the unknown expectation and standard deviation by their estimates from Table 2, we obtain:

   $P \sim N(85.97, 8.11)$ in case of Cracker-A variety of flour (2)

   $P \sim N(65.83, 4.34)$ in case of Snack-B variety of flour (3)

   The one-sided confidence intervals for P with bounds at $\pm 2\sigma$ for the two given varieties of flour are listed below.

Table 6: Confidence intervals for tenacity(P)

Tenacity(P)	**Snack-B variety**	**Cracker-A variety**
Conf. Interval ($\pm 2\sigma_Y$)	$(-\infty, 72.54]$	$[69.75, +\infty)$

7.5 Segregation Rule and Chance of Misclassification

In order to find out a suitable criteria for segregation of flour into one of the two varieties, the results explained above were taken into consideration. The rule, thus formulated, is as follows:

Select the particular consignment of flour for

a) Snack-B variety, if tenacity(P): $P \leq 72.54$

b) Cracker-A variety, if tenacity(P): $69.75 \leq P$

Unfortunately, this segregation rule for selecting the flour variety prior to processing admits not in each case a unique decision. If the tenacity(P) value falls within the interval [69.75, 72.54], then a flour consignment for both types of crackers is admitted, therefore the interval [69.75, 72.54] is called the indifference region of the classification procedure. Any value falling into this interval leads decision failure.

The probabilities for observing a value from the indifference region are easily calculated (see Annex A3):

Table 7: Probabilities of Decision Failures

	Flour: Cracker-A	Flour : Snack-B
$Prob\Big(69.75 \leq P \leq 72.54\Big)$	0.026	0.122

To reduce the failure probabilities, discussions were held with the technical personnel of the Quality Assurance Department and it revealed that Dry Gluten(%) could be the next quality parameter of flour for selection. In view of this fact, data were collected for Dry Gluten(%) for the two varieties of flour. The summary of the observations were found as follows :

Table 8: Summary of data on Dry Gluten(%)

	Flour: Cracker-A		Flour: Snack-B	
	Average	Std. Dev.	Average	Std. Dev.
$N = 40$	12.57	0.634	11.80	0.510
Conf. Int. (95%)	$[11.5272, +\infty)$		$(-\infty, 12.6389]$	

Unfortunately, the two confidence intervals overlap and again there is a indifference region given by the interval $[11.5272, 12.6389]$ admitting decision failures with following probabilities (for details see Annex A3):

Table 9: Probabilities of Decision Failures considering Dry Gluten(%)

	Flour: Cracker A	Flour: Snack-B
$Prob\Big(69.75 \leq P \leq 72.54\Big) Prob\Big(11.5272 \leq G \leq 12.6389\Big)$	0.01288	0.07987

7.6 Final Rules for Flour Classification

Considering both the tenacity(P) and Dry Gluten(%) properties of flour and adding a rule in case of indifference leads to the following revised and completed classification rule:

Select the particular consignment of flour according to the following rule:

a) Select Snack-B variety,

  a1) if $P < 69.75$, or

  a2) if $69.75 \leq P \leq 72.54$ and Gluten(%) < 11.5272, or

  a3) with probability 0.5 if $69.75 \leq P \leq 72.54$ and $11.5272 \leq$ Gluten(%) ≤ 12.6389.

b) Select Cracker-A variety,

  b1) if $P > 72.54$, or

  b2) if $69.75 \leq P \leq 72.54$ and Gluten(%) > 12.6389, or

  b3) with probability 0.5 if $69.75 \leq P \leq 72.54$ and $11.5272 \leq$ Gluten(%) ≤ 12.6389.

This decision rule allows in each case a unique decision, although in some cases by randomization only. Randomization could be performed, for example, by throwing a coin.

8 Expected Benefit

In view of this new methodology for flour testing developed, there would be a significant improvement in cost with respect to enormous time saving for flour testing, selection of every consignment of flour for a particular variety with a higher precision and accuracy and above all possibility of developing mutually beneficial supplier relationship for the entire organization.

9 Conclusions and Recommendations

(a) It would be worthwhile to determine more carefully, i.e., with a much higher sample size, the probability distribution of tenacity (P) of flour with respect to Cracker-A and Snack-B varieties.

(b) Although extremely strange, the result of the ANOVA should prompt management to examine the training of the inspectors to handle the Alveograph NG technique.

c) It should be checked whether a genuine classification procedure as described in [1] based only on tenacity (P) (or at least without randomization) could replace the rather complicated and eventually time-consuming three-step procedure proposed above.

(d) The misclassification probability, which depends on the assumed confidence levels and on the delivery probabilities for Cracker-A and Snack-B varieties should be estimated.

10 Implementation

Preliminary results of the study were discussed with the concerned technical personnel of the company and presented in the Steering Committee meeting. The implications of the study were highly appreciated and the entire methods of sampling, testing and decision making for appropriate selection of flour through Alveograph NG has been approved for as a routine practice in the entire branch of the organisation. It was reported that after usage of the classification rules for flour, the quality related problems during processing was reduced substantially.

References

[1] von Collani, E. (2004): Empirical Stochastics. In *Defining the Science of Stochastics.* Ed. E.v.Collani, Heldermann, Lemgo, 175-212.

Annex A1

Flour Characteristic: Tenacity (P)

A: Test for equality of variances

$$H_0 : \sigma^2_{\text{Snack-B}} = \sigma^2_{\text{Cracker-A}} \quad \text{vs.} \quad H_1 : \sigma^2_{\text{Snack-B}} > \sigma^2_{\text{Cracker-A}}$$

$$F_0 = \left(\frac{8.11}{4.34}\right)^2 = 3.49 > F_{0.05,11,11}$$

$$\Rightarrow \quad H_0 \text{ is rejected}$$

B: Test for equality of means

$$H_0 : \mu_{\text{Snack-B}} = \mu_{\text{Cracker-A}} \quad \text{vs.} \quad H_1 : \mu_{\text{Snack-B}} > \mu_{\text{Cracker-A}}$$

$$t_0 = \frac{y_1 - y_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} = 7.58 > t_{0.05,17}$$

$$\Rightarrow \quad H_0 \text{ is rejected}$$

Flour Characteristic: Extensibility (L)

C: Test for equality of variances

$$H_0 : \sigma^2_{\text{Snack-B}} = \sigma^2_{\text{Cracker-A}} \quad \text{vs.} \quad H_1 : \sigma^2_{\text{Snack-B}} \neq \sigma^2_{\text{Cracker-A}}$$

$$F_0 = \left(\frac{6.45}{4.28}\right)^2 = 2.27 < F_{0.025,11,11}$$

$$\Rightarrow \quad H_0 \text{ is not rejected}$$

D Test for equality of means

$$H_0 : \mu_{\text{Snack-B}} = \mu_{\text{Cracker-A}} \quad \text{vs.} \quad H_1 : \mu_{\text{Snack-B}} \neq \mu_{\text{Cracker-A}}$$

$$|t_0| = \frac{|y_1 - y_2|}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} = 4.48 \cdot 10^{-3} < t_{0.025,20}$$

$$\Rightarrow \quad H_0 \text{ is not rejected}$$

Annex A2

Model

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk} \tag{4}$$

where

$i = 1, 2$ [number of sample bags: $a = 2$]

$j = 1, 2$ [number of inspectors: $b = 2$]

$k = 1, 2, 3$ [number of test replications: $c = 3$]

Formulae :

$$\text{Correction Factor } (C.F.) = \frac{(\sum_i \sum_j \sum_k Y_{ijk})^2}{a \cdot b \cdot n}$$

$$\text{Total Sum of Squares } (TSS) = \sum_i \sum_j \sum_k Y_{ijk}^2 - C.F.$$

$$\text{Sum of Squares due to sample bags } (SSA) = \sum_i \frac{Y_{ijk}^2}{b \cdot n} - C.F.$$

$$\text{Sum of Squares due to inspectors } (SSB) = \sum_j \frac{Y_{ijk}^2}{a \cdot n} - C.F.$$

Sum of Squares due to combinations of sample bag and inspector

$$(SSAB) = \sum_i \sum_j \frac{Y_{ijk}^2}{n} - C.F.$$

Sum of Squares due to random error $(SSE) = TSS - (SSA + SSB + SSAB)$

Factor	R 2 i	R 2 j	R 3 k	Expected Mean Square
α_i	1	2	3	$\sigma^2 + 3\sigma_{\alpha\beta}^2 + 6\sigma_{\alpha}^2$
β_j	2	1	3	$\sigma^2 + 3\sigma_{\alpha\beta}^2 + 6\sigma_{\beta}^2$
$(\alpha\beta)_{ij}$	1	1	3	$\sigma^2 + 3\sigma_{\alpha\beta}^2$
ϵ_{ijk}	1	1	1	σ^2

Annex A3

Case 1: Without Considering Dry Gluten(G)%

A classification failure occurs if the tenacity(P) value falls within he interval [69.75, 72.54]. Thus, we obtain the following probabilities of classification failure.

- $Prob(\text{Failure}_P|\text{Cracker-A})$ = Probability of a classification failure in case of Cracker-A flour

Assumption: $P \sim N(85.97, 8.11)$

$$\begin{aligned} Prob(\text{Failure}_P|\text{Cracker-A}) &= Prob\Big(69.75 \leq P \leq 72.54\Big) \\ &= \Phi\left(\frac{72.54 - 85.97}{8.11}\right) - \Phi\left(\frac{69.75.57 - 85.97}{8.11}\right) \\ &= 0.0261 \end{aligned}$$

- $Prob(\text{Failure}_P|\text{Snack-B}) \;=\;$ Probability of a classification failure in case of Snack-B flour

Assumption: $P \sim N(65.83, 4.34)$

$$\begin{aligned} Prob(\text{Failure}_P|\text{Snack-B}) &= Prob\Big(60.75 \le P \le 72.54\Big) \\ &= \Phi\left(\frac{72.54-65.83}{4.34}\right) - \Phi\left(\frac{69.83-65.83}{4.34}\right) \\ &= 0.1222 \end{aligned}$$

Hence, the total probability of a classification failure if the procedure is based on tenacity(P) alone is given by:

$$Prob(\text{Failure}_P) = 0.0261 Prob(\text{Cracker-A flour}) + 0.1222 Prob(\text{Snack-B flour})$$

where $Prob$(Cracker-A flour) is the probability that a Cracker-A flour is delivered and $Prob$(Snack-B flour) that a Snack-B flour is delivered.

Case 2: With Considering Dry Gluten(G)%

Considering Gluten(G)(%) a classification failure occurs if $P \in [69.75, 72.54]$ and simultaneously $G \in [11.53, 12.64]$.

- $Prob(\text{Failure}_G|\text{Cracker-A}) \;=\;$ Probability of a classification failure with Gluten(G) in case of Cracker-A flour

Assumption: $G \sim N(12.57, 0.634)$, P and G statistically independent random variables.

$$\begin{aligned} Prob(\text{Failure}_G|\text{Cracker-A}) &= Prob\Big(60.75 \le P \le 72.54\Big) Prob\Big(11.53 \le G \le 12.64\Big) \\ &= 0.0261 \left[\Phi\left(\frac{12.64-12.57}{0.634}\right) - \Phi\left(\frac{11.53-12.57}{0.634}\right)\right] \\ &= 0.0261 \cdot 0.4933 \\ &= .01288 \end{aligned}$$

- $Prob(\text{Failure}_G|\text{Snack-B}) \;=\;$ Probability of a classification failure with Gluten(G) in case of Snack-B flour

Assumptions: $G \sim N(11.80, 0.510)$, P and G statistically independent random variables.

$$\begin{aligned} Prob(\text{Failure}_G|\text{Snack-B}) &= Prob\Big(60.75 \le P \le 72.54\Big) Prob\Big(11.53 \le G \le 12.64 Big) \\ &= 0.1222 \left[\Phi\left(\frac{12.31-11.80}{0.510}\right) - \Phi\left(\frac{11.94-11.80}{0.510}\right)\right] \\ &= 0.1222 \cdot 0.6536 \\ &= 0.07987 \end{aligned}$$

Hence, the total probability of a classification error, if Dry Gluten(G)(%) is additionally considered, is give by

$$Prob(\text{Failure}_G) = 0.01288 Prob(\text{Cracker-A flour}) + 0.07987 Prob(\text{Snack-B flour})$$

Prasun Das and Susanta Kumar Gauri
SQC & OR Unit
Indian Statistical Institute
27B Camac Street
Kolkata-16
India
dasprasun@hotmail.com