Dependence of flour yield on moisture content of chickpea seeds

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Abstract

Introduction. The aim of the study was to determine the effect of chickpea seed moisture on the yield of flour (sieve mesh size 132 µm) obtained in hammer and roller mills.

Materials and methods. Primary crushing of chickpea seeds was performed in a hammer mill with a sieve hole diameter of 4 mm and a hammer rotation speed of 80 m/s. Chickpea seeds were crushed in a roller mill using corrugated and smooth rollers with three crushing and grinding systems. After each system, the flour was separated and the flour yield was determined in relation to the initial weight of the seeds.

Results and discussion. Grinding dry chickpea seeds with 8.9% moisture content in a hammer mill yielded 10.5% flour. Increasing the chickpea moisture content to 11.6% increased the flour yield to 11.9%. Further increasing the chickpea moisture content decreased the flour yield (132 µm sieve pass). The optimum moisture content was 11.5%. The highest flour yield was 12.0% with a moisture content of 11.5%. The total flour yield from chickpea seeds crushed in a roller mill was only 50.6% (sieve pass 132 µm).

The flour yield on 2- and 3- crushing systems was only 1.0% and 1.2%, respectively. This means that these break systems with corrugated rollers are not practical to use due to the low flour yield.

To obtain a higher yield of chickpea flour, it is necessary to increase the number of milling systems. It was not possible to completely grind the chickpea kernel and achieve the maximum possible flour yield from the kernel due to the insufficient length of the roller installation line (3- crushing systems).

Analysis of the cumulative flour whiteness curve shows that with increasing flour yield, its whiteness decreases from 39.8 to 27.0 units. It indicates that the flour quality decreases with increasing flour yield.

Conclusion. For intermediate crushing of chickpea seeds with subsequent crushing on smooth rollers, one crushing system is sufficient. For more complete crushing of chickpea seeds, it is necessary to increase the number of crushing systems.

Introduction

Chickpeas (*Cicer arietinum* L.) are the second most popular legume in the world after beans. Chemical composition of chickpea includes, % of dry matter (DM): crude protein, 22.76-24.63; crude fiber, 6.49-9.94; nonfibrous carbohydrate, 46.81-49.13; starch, 38.48-39.12; soluble sugars, 7.53-8.43; total phenolic compounds, 0.26-0.27 (Maheri-Sis et al., 2008; Rachwa-Rosiak et al., 2015). Content of lipids in chickpeas varies from 3.10 to 5.67% DM containing mostly unsaturated fatty acids linoleic and oleic acids (Grasso et al., 2022). Chickpeas also contain minerals (potassium, phosphorus, calcium, magnesium, iron, and zinc) (Jukanti et al., 2012) and water- soluble vitamins such as vitamin C, riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), and folic acid (B9). Fat-soluble vitamin A and vitamin E (α-and γ tocopherols) as well as vitamin K are reported to be present in chickpeas (Noordraven et al., 2021; Wang et al., 2021). Chickpeas have been found to have a variety of beneficial properties including antidiabetic, anticancer, antihypertensive and antioxidant activities (Li et al., 2024; Begum et al., 2023). Flour produced from chickpeas is a valuable product being used in preparation of different functional food (Augustin et al., 2024; Buresova et al., 2017; Goranova et al., 2020; Noordraven et al., 2021; Stabnikova et al., 2021).

The technology of grinding chickpea seeds is of great importance when processing them into flour (Figure 1).

Figure 1. Chickpea seeds and flour

One of the indicators of the efficiency of the grinding process is the total yield of flour, and it is important for assessing the use of the potential of the processed grain (Martin et al., 2022). In the production of flour, the initial task is to separate the chickpea seeds from the husk. It has been shown that the husk can be easily separated from the kernel after soaking the chickpea seeds (Martin et al., 2022). The separated chickpea seeds can be easily processed into fine flour. However, it is not known what length of roller mill is required to completely grind the chickpea kernels into fine flour and obtain a particle size of less than 132 µm (Martin et al., 2022). The sieve size of 132 µm is taken by analogy with the production of premium wheat flour, which is also obtained by passing through sieves with openings of this size (Finnie and Atwell, 2016).

Shutenko et al. (2014) studied the process structures of chickpea seed grinding into the roller mills with corrugated rollers. They proposed to grind whole chickpea seeds and cracked chickpea into grist (particle size range from 1000 μm to 219 μm) with the aim the next grinding this grist into flour. It was noted that it is possible to obtain 83-84 % of grist and only 15-16 % flour (sieve passage with 219 μm openings). This research does not answer the question of what maximum flour yield from chickpea seeds can be reach in general. The proposed methods of chickpea grinding are only part of the initial stage of grinding.

Martin et al. (2022) conducted a study on milling whole and cracked chickpea seeds into flour using a pilot scale facility that consisted of roller mills, cleaners, and plansifters. Two types of chickpea flour were obtained. The first type was the coarse flour with the particle size between 315 μm and 150 μm. The second type was a fine flour with the particle size below 150 μm. The yield of coarse flour ranged from 54.07 to 63.8%. The yield of fine flour ranged from 16.03 to 23.9%. The total flour yield ranged from 70.1 to 87.7% depending on the chickpea variety.

A specific feature of these studies was the use of purifiers in the chickpea seed grinding process, which made it possible to significantly influence the efficiency of chickpea seed grinding. Martin et al. (2022) noted that chickpea seed moisture of 11.0 % was optimal for separation of the hull. In their studies, chickpea seeds had a moisture content of 10.9 %, for this reason they did not moisten the seeds. The researchers did not study the effect of moisture on grinding efficiency. However, humidification of chickpea seeds can have a very different effect on milling efficiency. When moisture penetrates the grain, the water creates stresses that weaken the bonds between protein compounds and starch (Pasha et al., 2010). Martin et al. (2022) also emphasized that the hulls are obtained after milling and did not consider the possibility of separating the hulls before milling.

Tikle and Mishra (2018) investigated the characteristics of different chickpea varieties and showed that the *dal* yield ranged from 66 to 71%. The biggest limitation of their study is the lack of sieve characteristics that would give an indication of the particle size of the milled product.

Thus, the effect of chickpea seed moisture on the fine grinding yield remains unexplored. An important issue is the effect of pre-grinding of chickpea seeds on the fine milling process. The aim of the present study was to determine the effect of moisture content on the flour yield from chickpea seeds and the efficiency of grinding chickpea seeds into flour using pre-grinding in a hammer mill and roller milling.

Materials and methods

Materials

Chickpea seeds were used with the following quality characteristics: bulk density, 789±2.5 g/l; original seed moisture content, 8.9±0.19 %; mass of 1000 seeds, 402±1.6 g.

Methods

Chickpea seeds were ground in two stages. Chickpea flour yield after grinding in the hammer mill was explored on the first stage at seed moisture content was changing. In the second stage the pre-ground products were ground in the roller facility. The need to grind chickpea seeds in a hammer mill is due to the fact that large seeds are not captured by the rollers. The whole seeds require destruction into smaller particles for further grinding by the rollers.

Grinding chickpeas in hammer mill

The study of the effect of chickpea seed moisture on the yield of flour during grinding in a hammer mill was carried out using the following method. Dry chickpea seeds of weight 400 g were poured into four containers and the calculated amount of water was added to the seeds. Seeds were tempered for 24 hours at room temperature.

The required chickpea moisture content was taken at 11.0, 13.0, 15.0 and 16.0%. 300 g chickpea seeds were taken from each containers after the tempering in order to grind in the hammer mill. The remaining seeds were used to determine their moisture content. The actual moisture content was determined according to ISO 712:2009 (E). "Cereals and cereal products. Determination of moisture content" (ISO, 2009). The moistening was performed with water at room temperature.

Water amount, which was added to chickpea seeds calculated by following equation (Kharchenko et al., 2022):

$$G_w = G_g\left(\frac{W_1 - W_0}{100 - W_1}\right), \tag{1}$$

where G_w, G_g –water weight and dry chickpea seed weight respectively, g; W_0, W_1 –initial and required moisture content of chickpea seeds respectively, %.

Grinding was performed by the hammer mill with the screen that had the diameter of openings of 4.0 mm. The hammer mill had a vertical situated motor. The cross-shaped hammers were fixed to the shaft of the motor. Rotate speed of hammer edges was ≈ 80 m/s (Figure 2).

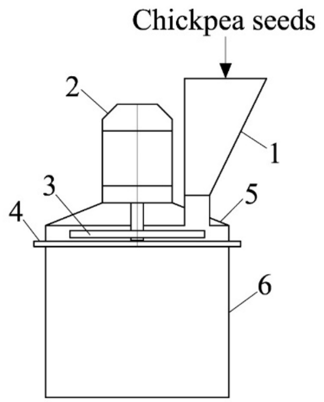

Figure 2. **Laboratory hammer mill**:
1 – grain hopper; 2 – motor; 3 – hammer; 4 – screen;
5 – hammer body; 6 – hopper for grinded products

After optimal moisture content was defined, chickpea seeds were moistened and ground by the hammermill. The ground products were directed to roller facility LM-2.

The ground product was sifted by the lab sieve kit according to the method, which described by the paper (Kharchenko et al., 2021). Particles of ground product, which passed through the 132 µm sieve were attributed to fine flour.

Chickpea seeds milling by roller facility

Chickpea seeds milling by the roller facility LM-2 (Elelmiszeripari Gepgyar, Budapest, Hungry) (Ulmer, 2014) was performed using the next method. Chickpea seeds with weight of 2.1 kg were moistened to moisture content of 11.5 % with next tempering for 24 hours. Water amount was calculated using equation 1. Moistened chickpea seeds were ground by the hammer mill with the screen, which had a diameter of openings of 4.0 mm. Fine flour was obtained through a sieve passage of 132 µm. The products remaining on the sieve were directed to the receiving hopper of the roller facility LM-2. The research flow sheet shown in Figure 3.

All ground products were collected to the individual containers during milling. All collected products were weighed and calculated into percentages. A distance between I break rollers was 0.4 mm, II break rollers – 0.25 mm, and III break rollers – 0.1 mm. The distance between reduced system rollers was established as the smallest of 0.05 mm. The distances were established by the manual tare probe.

After flow yield was established in the individual flows the flour whiteness was conducted by the VBB-1MK device (Motom, Lviv, Ukraine). The cumulative flour whiteness curve was calculated based on the output values of the obtained streams and their whiteness using the formula (Sakhare and Inamdar, 2014):

$$\bar{W} = \frac{\sum_{i=1}^{N}(Y_i \times W_i)}{\sum_{i=1}^{N} Y_i} \qquad (2)$$

where Y_i, W_i are flour yield value (in %) and whiteness of each flour flow (units), respectively.

Statistical analysis

The weighted average particle size of the ground seeds is a characteristic of the grinding efficiency. The weighted average particle size d_k of all ground product was calculated by follow equation (Brandt, 2014):

$$d_k = \frac{m_1 d_1 + m_2 d_2 + \ldots + m_i d_i}{m_1 + m_2 + \ldots + m_i} \qquad (3)$$

where m_1, m_2, m_i are productamount of each fraction, %; d_1, d_2, d_i are average particle size of each fraction, which was defined as half the sum of the sizes of the sieve openings, µm, respectively.

Scattering measure of ground product particle size is standard deviation S, which was calculated by follow equation (Chornyi et al., 2021):

$$S = \pm\sqrt{\frac{\sum_{i=1}^{n} m_i x_i^2}{\sum_{i=1}^{n} m_i} - \left| -\frac{\sum_{i=1}^{n} \bar{m}_i \bar{x}_i}{\sum_{i=1}^{n} m_i} \right|} \qquad (4)$$

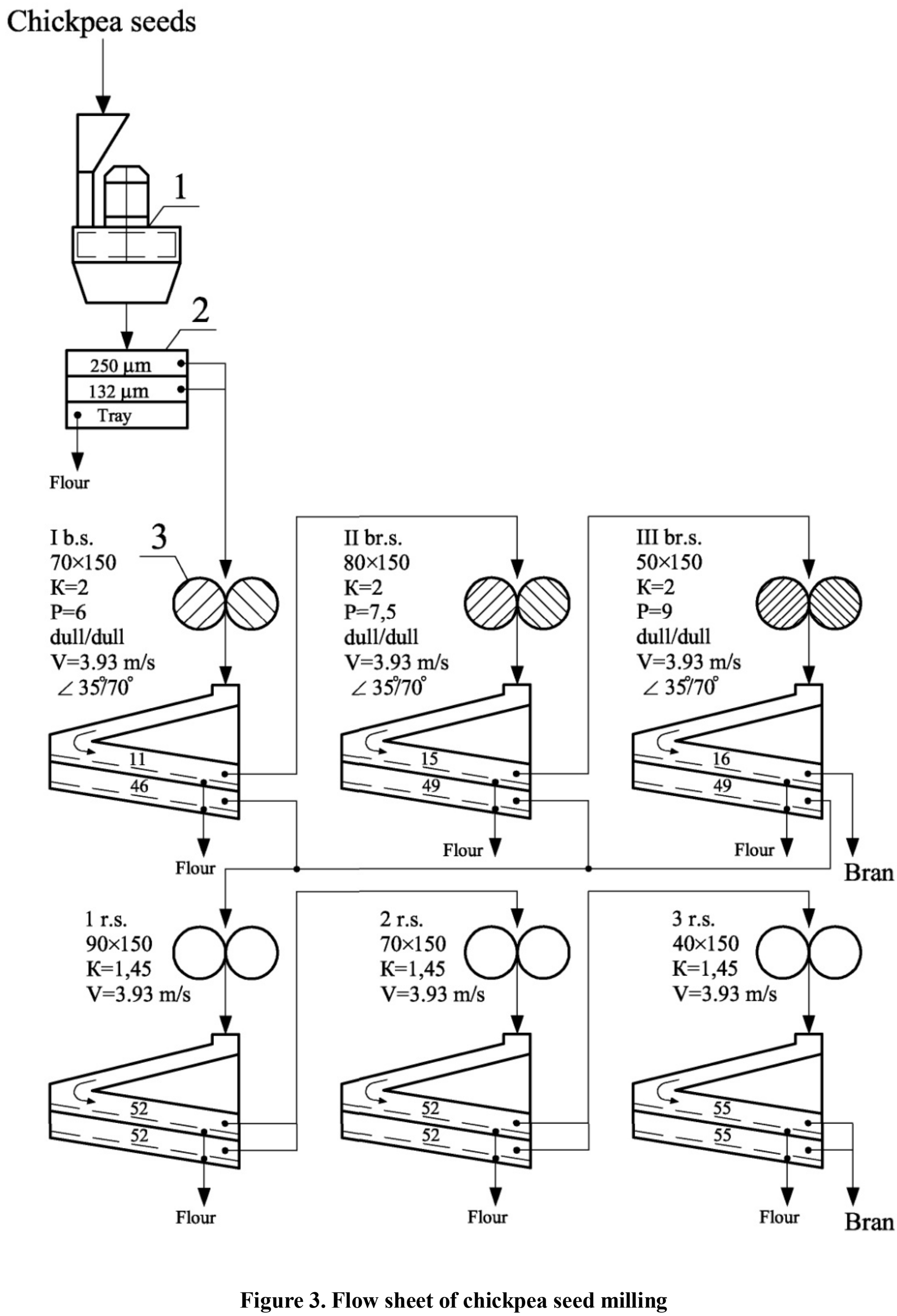

Figure 3. Flow sheet of chickpea seed milling
1 – hammermill with screen of diameter 4.0 mm; 2 – laboratory sieve kit; 3 – laboratory mill

Results and discussion

Chickpea seed milling of hammer mill

Research has shown that dry chickpea seeds are ground by the hammer mill with a low flour yield. Most ground products with particle size up to 1000 μm have a yield of less than 10 %.

Analysis of flour yield during grinding in the hammer mill (Figure 4) showed that with an increase in chickpea seed moisture content from 8.9 % to 11.0 %, flour yield increases. An increase in chickpea seed moisture content to 15.8 % leads to a decrease in flour yield. This indicates that there is an extremum point at which flour yield is the highest.

Research of flour yield (sieve passage 132 μm) confirmed the hypothesis of the presence of an extremum point at different moisture content (Figure 4).

The parabola shown in Figure 4 is approximated by a second-order equation:

$$B = -0.213W^2 + 4.907W - 16.183 \tag{5}$$

where B is flour yield (sieve passage 132 μm), %; W is chickpea seed moisture content, %.

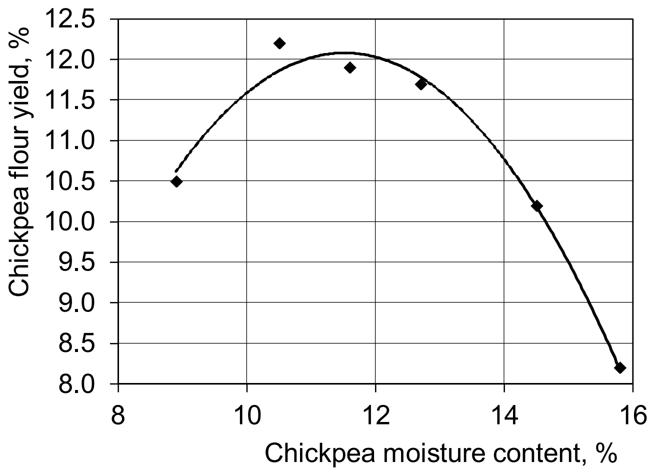

Figure 4. Effect of chickpea moisture content on flour yield

The correlation coefficient was R = 0.991, that indicates a special high relation between the studied values.

It is of practical interest to determine the chickpea moisture content when the flour yield is the highest. To find the extremum point, differentiate equation 5 and set it equal to zero:

$$\frac{dB}{dW} = -2 \cdot 0,213W + 4.907 = -0.426W + 4.907$$

$$-0.426W + 4.907 = 0$$

$$-0.426W = -4.907$$

$$W = \frac{4.907}{0.426} = 11.5\ \%$$

where B is flour yield (sieve passage 132 μm), %; W is chickpea seed moisture content, %.

Mathematical analysis showed that the optimal moisture content at which the highest yield of flour from chickpea seeds is W = 11.5 % at a screen opening size in the hammer mill of 4.0 mm (Ravi and Harte, 2009).

Substituting the obtained value into equation 5, the flour yield is calculated:

$$B = -0.213 \cdot 11.5^2 + 4.907 \cdot 11.5 - 16.18 = -28.169 + 56.43 - 16.18 = 12.0 \ \%$$

The highest flour yield at a moisture content of 11.5 % will be 12.0 %. This value was also confirmed experimentally. It is likely that at that moisture content the highest flour yield will be observed, when chickpea seeds will grind by a roller mill. This phenomena is due to the fact that chickpea moisture content directly affects the elastic-plastic properties of chickpea seeds (Dobraszczyk et al., 2002), and not the grinding method.

Since the average particle size of the ground mixture characterizes the grinding efficiency, studies were conducted on the weighted average particle sizes of the ground chickpea seed mixture. The results also confirmed that with an increase in moisture content from 12.7 % to 15.8 %, the efficiency of the chickpea seed grinding process in a hammer mill decreases. The results of the studies shown in Table 1.

Table 1

Chickpea grinding efficiency in the hammer mill at the different moisture content

Moisture content in chickpea seeds, %	Average particle seize of the mixture, µm	Flour yield, %
8.9±0.19	1623.0±1032.8	10.5
10.4±0.68	1586.7±1042.7	12.2
11.6±0.09	1623.4±1032.8	11.9
12.7±0.05	1625.4±1039.3	11.7
14.5±0.16	1728.6±1012.3	10.2
15.8±0.11	1754.4±998.5	8.2

Based on the above analysis, it can be concluded that the optimal moisture content for chickpea seeds is W = 11.5 %. At this moisture content, a flour yield of 12.0 % was obtained. Studies also confirm the fact that the best moisture content for chickpea seeds is in the moisture range of 11.0 % (Martin et al.,2022).

During the screening of the grinding products obtained in the hammer mill, it was noticed that a significant part of the hulls remained on the sieve with holes Ø2.0 mm. It is advisable to direct the outlet of the sieve Ø2.0 mm into the air separator in order to separate the hulls from the kernel particles.

The hammer mill is not able to grind chickpea seeds into flour, which has a particle size of less than 132 µm. Whole chickpea seeds grinding by the hammer mill is an important step in chickpea seed grinding technology. This stage allows to break the relations between the anatomical parts of seeds and promotes better separation of the hulls before the fine grinding by the roller mill.

In order to more completely extract the chickpea seed kernel, products remaining on the sieve were ground in a LM-2 roller mill. Pre-grinding of chickpea seeds by a hammer mill is also necessary so that the rollers of the roller mill better capture the chickpea kernel when these products enter between the rollers. Whole chickpea seeds are not captured by the rollers when the seeds enter the inter-roller space and the grinding process stops. Whole seeds cannot be destroyed.

Chickpea flour milling by the roller mill LM-2

Research of the chickpea seed flour yield by the LM-2 roller mill showed that chickpea seeds cannot be ground into flour with particle sizes less than 132 µm (sieve passage 132 µm) with maximum yield unless the length of the roller line is increased. Research results showed in Table2.

Table 2

Milled product yield of chickpea seeds in the roller mill LM-2

Products	Chickpea flour yield, %	Flour whiteness
Hammer mill	12.0	34.4±0.4
I break system	2.42	29.5±1.2
II break system	1.0	27.0±1.7
III break system	1.2	28.2±1.2
1 reduce system	7.51	32.4±1.6
2 reduce system	3.75	33.4±0.3
3 reduce system	3.81	39.8±1.3
Sorting system	18.9	29.3±1.8
Σ	50.6	
Bran	6.5	–
Meal	41.16	–
Aspiration waste	1.74	–
Σ	100	

The moisture content was 13.0 ± 0.05 % during the grinding of chickpea seeds. Chickpea seed moisture content was 1.5 % higher than optimum (Martin et al., 2022) established above.

The calculated amount of water was added to chickpea seeds to increase their moisture content from 8.9 % to 11.5 % during the moistening. The actual moisture content turned out higher than the calculated one. It can be explained by the significant hydrophilicity of the chickpea seeds. Accordingly, the flour yield in the hammer mill was obtained somewhat less than the maximum possible. However, the actual flour yield in the hammer mill was 11.1 %, and the calculated flour yield according to formula 5 is 11.6 %. Close values indicate the adequacy of the obtained dependence for large chickpea seeds.The total flour yield (sieve passage 132 µm) was 50.6 %, which is only half of the total amount of seeds directed to grinding. It should be noted that 38.6 % of flour was obtained by the roller mill LM-2, and 12.0 % of flour was obtained in the hammer mill. This indicates that seven grinding systems are not sufficient for complete grinding of chickpea seeds into flour. The products of third break system have not increased the chickpea flour yield.

However, the obtained results provide valuable information for organizing the technological process of chickpea seed milling into fine flour. Among the grinding roller systems, the highest flour yield was obtained by the reducing systems. However, three reducing systems are not enough for complete grinding of chickpea seeds into flour.

Based on the conducted research, the following conclusions can be drawn on the organization of the technological process of chickpea seeds grinding into flour. It is necessary to install the plansifter to separate the flour from other products After chickpea seeds were grinding into flour by the hammer mill with a screen which has the holes Ø4.0 mm. In addition, the receiving sieve should be the screen with holes Ø2.0 mm. Installing such a screen will allow separating large products from small ones, and the seed hulls are also separated together with the coarse product.

It is advisable to direct the coarse product from the screen with holes Ø2.0 mm to the air separator. This will separate the light hulls from the large particles and reduce the turnover of products in the technological process. Whole particles should be directed to the roller mill of the I break system.

It is clear from the data in Table 2 that the II and III break systems were extracted the flour with the yield of 1.0 % and 1.2 %, respectively. Such insignificant flour yields may indicate that these systems are unnecessary in the technological process of chickpea seed milling and all obtained those products should direct to 1 reduce system.

Product remaining on the sieve of 3 reducing system was sieved by control sieve (132 µm) for the target of additional flour extraction. This is due to the fact that the screening surface of the LM-2 plansifter is not sufficient for complete screening of milling products. Therefore, it can be recommended to additionally re-screen those products in an additional sorting system. When organizing the technological process of an industrial plant, a sorting system is also necessary for screening aspiration waste. It is important to allocate a sifting surface for flour control.

Based on the data in Table 2, it can be seen that the flour is 41.16 %. This product is chickpea seed kernel and hulls, which is obtained as a residue on the sieve from the three reduce system. The obtained amount is large. It indicates that it is advisable to allocate three more grinding systems with micro-rough rollers to grind this amount of products. At the same time, the main amount of coarse bran remains in the break process.

The flour whiteness was determined for each flour stream, the whiteness values are given in Table 2. A cumulative weighted average whiteness curve was constructed based on the flour yields and their whiteness, which is given in Figure 4.

The results shown in Table 2 indicate that chickpea seeds can be ground into fine flour without the use of the purifiers. The total yield of fine flour can be obtained more than 23.9 % (Martin et al., 2022).

Chickpea whiteness

The flour whiteness was determined for each flour stream, the whiteness values are given in Table 2. A cumulative weighted average whiteness curve was constructed based on the flour yields and their whiteness, which is given in Figure 5.

Analysis of the chickpea flour whiteness showed that with increasing flour yield, the whiteness decreases. This phenomena can be explained by the fact that the whiteness of flour is a quantity inversely proportional to the ash content, therefore, with a decrease in the whiteness of flour, the ash content of its flows increases (Kalitsis et al., 2021). In turn, this indicates an increase in the flour of hull and high-ash products.

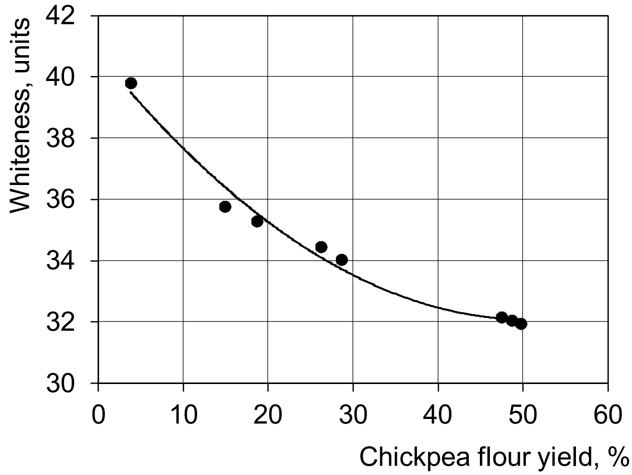

Figure 5. Cumulative curve of chickpea flour whiteness

Flow sheet of chickpea seed milling

A flow sheet for grinding chickpeas into flour is proposed. The flow sheet is shown in Figure 6.

The proposed flow sheet uses the stage of pre-grinding chickpea seeds. Since some of the hulls are separated before fine milling, this circumstance allows not to use purifiers when milling chickpea seeds into fine flour as is done by Martin et al. (2022).

The technological process involves the use of the hammer mill, air separator, roller mills, centrifugal impactor, and plansifters. The use of centrifugal impactors helps to increase the extraction of flour from intermediate products. However, the presented flow sheet of the chickpea seed grinding process requires further experimental confirmation on an industrial scale. The use of centrifugal impactors allows the increasing of flour extraction from intermediate milling products.

The proposed flow sheet has a shortened break process and an expanded fine reducing process into fine flour.

Conclusions

The optimum moisture content of chickpea seeds for hammer milling is 11.5%. At this moisture content, the flour yield was 12.0%. Increasing the moisture content of chickpea seeds reduces the flour yield from 12.0% to 8.2%.

Grinding of chickpea seeds in a hammer and roller mill gives a flour yield of 50.6% (sieve pass 132 µm). Complete grinding of chickpea seeds into fine flour was not possible due to the short length of the roller mill line LM-2.

Using a hammer and roller mill, it is possible to obtain flour of 50.6% (sieve pass 132 µm). Complete grinding of chickpea seeds into fine flour could not be achieved due to the short length of the roller line of the laboratory roller mill.

Analysis of flour yield and whiteness showed that increasing the flour yield reduces flour whiteness from 39.8 to 27.0 units. This indicates a deterioration in the quality of the flour.

Pre-grinding of wet chickpea seeds in a hammer mill allows the separation of large particles of husk, which can be useful for improving the quality of flour.

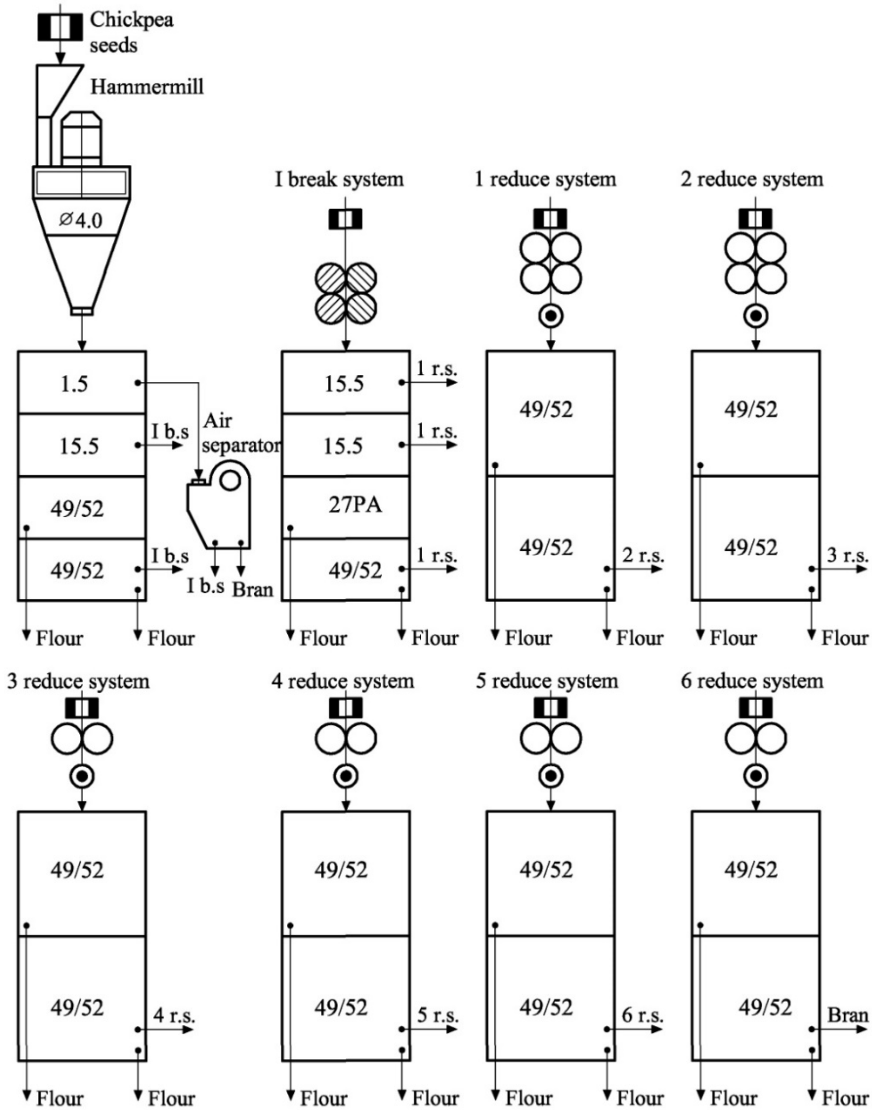

Figure 6. Referential flow sheet of chickpea seeds milling to fine flour

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