TECHNICAL NOTE

Mechanical dewatering of chopped alfalfa using an experimental piston-cylinder assembly

S. SINHA[1], S. SOKHANSANJ[1], W. J. CRERAR[1], W. YANG[1], L.G. TABIL[1], M.H. KHOSHTAGHAZA[2] and R.T. PATIL[3]

[1]Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK, Canada S7N 5A9; [2]Tarbiat Modarress, Tehran, Iran; and [3]Central Institute of Agricultural Engineering, Bhopal, India. *Received 10 December 1999; accepted 31 May 2000.*

Sinha, S., Sokhansanj, S., Crerar, W.J., Yang, W., Tabil, L.G., Khoshtaghaza, M.H. and Patil, R.T. 2000. **Mechanical dewatering of chopped alfalfa using an experimental piston-cylinder assembly.** Can. Agric. Eng. 42:153-156. Experiments were conducted to investigate the quantity and quality of the chopped alfalfa pulp and juice extracted in a piston-cylinder assembly. Single- and double-macerated alfalfa chops at an initial moisture content of 75.7% (wet mass basis) were pressed under constant or increasing pressures up to 20 MPa. The pressed pulp and the juice were analyzed for the contents of dry matter, protein, and β-carotene. Approximately 52% of the total water content was removed at pressures higher than 4 MPa. The pressure required to extract extra juice from already pressed pulp increased exponentially. The juice had on average solids content of 10-12% (dry mass basis). On a dry matter basis, there were no reductions in either protein content or β-carotene in the pulp. **Keywords**: alfalfa, lucerne, drying, dewatering, cylinder-piston, pressure, moisture content, β-carotene, protein.

Des expériences ont été faites pour étudier la quantité et la qualité de la pulpe et du jus extraits de luzerne hachée grâce à un assemblage piston-cylindre. De la luzerne hachée, ayant subi une macération simple ou une macération double, et dont la teneur en eau initiale était de 75.7% (base humide), a été pressée. La pression appliquée était constante ou allait en augmentant jusqu'à 20 MPa. On a analysé la teneur en matières sèches, en protéine et en β-carotène de la pulpe pressée et du jus. A des pressions supérieure à 4 Mpa, on a réussi à extraire 52% de la teneur en eau totale. La pression nécessaire à l'extraction de jus additionnel de la pulpe déjà pressée augmente de façon exponentielle. La quantité de solides contenus dans le jus était en moyenne de 10-12% (base sèche). En terme de pourcentage de matière sèche, les teneurs en protéine et en β-carotène de la pulpe n'ont pas diminué.

INTRODUCTION

Fresh alfalfa has a moisture content (m.c.) ranging from 70% to 85% wet mass basis (moisture contents in this paper are given in percent wet mass basis, unless otherwise specified) at the time of harvest. The optimum moisture content for pelleting is about 10%. The excess moisture is removed by partial sun drying in the field followed by artificial drying in a drying plant. Complete artificial drying at a high temperature (typically 800°C) tends to preserve vitamins thus it is preferred to sun drying. Artificial drying, however, is more expensive than pre-drying in the field. Bad weather may damage the crop during field-drying. Savoie et al. (1995) showed that alfalfa maceration enhances drying rates in the field resulting in reduced drying costs.

Mechanical dewatering as a pre-drying alternative deserves investigation. Hibbs et al. (1968) showed that mechanical dewatering eliminated an average of 60% of water in the standing crop. The percent protein in the dry matter of the dewatered alfalfa averaged 3.2% lower than that in the standing crop. When the crop was left in the field to wilt, the percent protein reduction averaged 1.8%. The loss of protein in the wilted material was more variable than mechanically dewatered alfalfa due to a variable leaf loss.

Holdren et al. (1972) determined that the required dewatering pressures ranged from 1.4 to 13.8 MPa depending on the degree of crop conditioning. The duration of dwell time varied from 0.5 to 10 min. The dry matter content of the juice remained constant irrespective of the quantity of juice expressed. The juice from minced alfalfa contained about 50% more dry matter than juice from chopped alfalfa. Koegel et al. (1973) performed three sets of experiments to study the effect of uniaxial force on the rupture of plant cells in alfalfa stems and leaves. Tests done at 0.35-27.6 MPa showed that pressure alone was not responsible for cell rupture in stems and leaves of alfalfa. Savoie and Beauregard (1990) studied the effects of initial moisture content, density, and number of macerations on the juice quality of alfalfa. The proportion of juice extracted increased from 10 to 21% when the alfalfa moisture content increased from 80 to 84%. Double macerations increased the extracted juice by 13-16%.

Past research shows that compressive stress, dwell time, initial moisture content, and the degree of crop maceration affects the amount of juice extracted from alfalfa. The reported experiments were generally performed by applying constant pressures on a fixed amount of material. For commercial application such as in a screw press, the material experiences continuously increasing compressive stress (Sinha 1995). Therefore, engineering data relating the varying pressures and the quantity and quality of the pressed pulp are important.

The objective of this research was to determine the effect of pressure on quantity and quality of fresh and pressed alfalfa chops and juice.

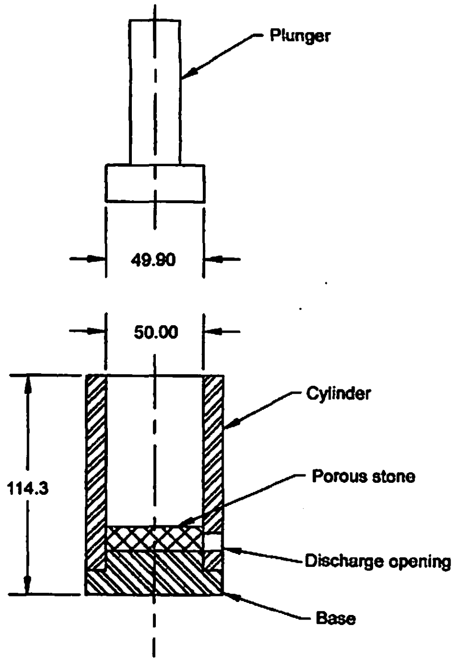

Fig. 1. Schematic diagram of piston cylinder used for pressing alfalfa chops.

MATERIALS and METHODS

Figure 1 is a schematic diagram of the piston-cylinder and the removable bottom flange used in these experiments. The internal diameter and the height of the cylinder were 50 mm and 114.3 mm, respectively. The piston had a clearance of 0.05 mm with the cylinder wall. A 10 mm orifice at the bottom of the cylinder provided a drain. Three 50 mm diameter porous bronze discs were placed on top of each other at the bottom of the cylinder to prevent the pressed pulp from draining out. A steel screen was then placed on the top of these porous discs to prevent blockage.

Freshly cut alfalfa variety Beaver (first cut) was placed in plastic bags and stored in a freezer (-20°C). To conduct the experiments, the frozen alfalfa was thawed at room temperature and hand cut into 50 mm pieces. The chops were macerated by passing them once or twice through a pair of grooved rollers. The cylinder was filled to the top. The piston was pressed into the filled cylinder using a motorized hydraulic press. The advancement of the piston was stopped when the flow of juice stopped or a target pressure was reached. Three series of tests were conducted.

Series one

Approximately 60 g of single-macerated alfalfa pieces were placed in the cylinder. Fourteen target pressures ranging from 1 to 30.8 MPa (1.0, 2.1, 3.1, 4.0, 5.1, 5.9, 8.3, 10.2, 13.2, 14.5, 16.5, 18.6, 20.7, 30.8 MPa) were tested. A material balance showed that some of the extracted juice was lost in the cylinder and inside the drain hose.

Series two

Alfalfa was macerated twice. A sponge was placed above the base of the piston to absorb residual juice passing through the cylinder-piston clearance. A larger drain hose with a pinch cock was used to prevent the back flow of juice. The quantity of alfalfa placed into the cylinder was increased to 65 g. Tests were conducted using nine target pressures: 2, 4, 6, 8, 10, 12, 14, 16.5, and 18.6 MPa.

Series three

Approximately 65 g of double-macerated alfalfa chops were placed in the cylinder. The pressure on the charge sample was increased progressively. For example, the chops were pressed from 0 to 2 MPa and maintained at 2 MPa until all of the expressed juice was collected. The pressed pulp was removed, placed in plastic bags, and stored in a freezer. The cylinder was refilled with the new material. The pressure was increased from 0 to 2 MPa. Once the flow of juice stopped, without removing the pulp, the pressure on the piston was increased to 4 MPa and maintained at this pressure to collect the juice in a separate cup. Since a smaller amount of juice was expressed in the 2-4 MPa range, the experiment was repeated five times in order to accumulate adequate juice for analysis. This procedure was repeated for higher pressure ranges of 4-6, 6-8, and 8-10 MPa and the juice was stored. The collected juice from each pressure range was frozen at –20°C and the pressed pulp was kept in a sealed plastic container in cold storage at 4°C until further analysis.

The pressed pulp, juice, and fresh alfalfa were analyzed for protein, β-carotene, and moisture content. The Saskatchewan Feed Testing Laboratory, University of Saskatchewan, Saskatoon, conducted the protein and β-carotene analyses. The moisture content of the fresh and pressed pulp was measured following the ASAE S358.3 oven method (ASAE 1997). The dry matter content of the juice was measured by evaporating the juice in the oven (104°C for 4 h) and weighing the remaining solids.

RESULTS

The data from the series one experiment showed a poor correlation coefficient (-0.45) between the pressures applied and the moisture content in the pulp. The mass of single-macerated chops charged into the cylinder was 60.4 g (standard deviation, sd=0.2 g, n=14). The pressed pulp yield was 38.3 g (sd=1.8 g, n=14) and the juice yield was 19.1 g (sd=2.4 g, n=14). The moisture content of the pulp was 70.7% with a large variation (sd = 10.0%, n=14). The reason for the large variation in moisture content was the loss of juice in the hose and cylinder and a possible re-mixing of juice with the pulp at the end of a pressure test.

Constant pressure tests

Table I presents the data from the second series of tests in which the chopped fresh alfalfa was macerated twice. The quantity of material charged into the cylinder increased to 65 g. The yield of juice increased progressively with increasing pressure. The corresponding moisture content of the pressed pulp decreased to less than 63.3% when pressures exceeded 4 MPa. Approximately 52% of the total water content was removed.

Koegel and Bruhn (1972) used Eq. 1 to relate the final moisture content of pressed alfalfa to the applied pressure.

$$Me = 48.3P^{-0.1746} \quad (1)$$

where:

P = applied pressure (MPa), and

Me = final moisture content (%wb).

Table I. Mass balance and moisture content of pulp after pressing alfalfa at 75.7% m.c. in the second series of tests.

Run no.	Pressure (MPa)	Initial mass (g)	Pulp yield (g)	Juice yield (g)	Pulp m.c. (% wb)
1	2.1	65.9	39.4	18.9	66.1
2	4.1	66.2	39.9	23.9	65.5
3	6.2	65.6	34.5	27.2	61.8
4	8.3	65.7	37.9	23.7	63.3
5	10.3	66.0	32.4	31.0	60.3
6	12.4	65.6	31.9	30.7	60.5
7	14.5	65.3	32.3	31.1	61.5
8	16.5	65.5	31.3	29.8	60.0
9	18.6	66.0	32.4	31.6	61.1

Table II. Average yield of pressed pulp and juice expressed from alfalfa chops at 75.7% m.c. for various pressure ranges in series three tests (standard deviations are in parenthesis).

Pressure range (MPa)	No. of samples	Fresh charge (g)	Pulp mass (g)	Juice mass (g)
0-2	3	65.5 (0.3)	36.4 (1.5)	20.8 (5.3)
2-4	5	65.6 (0.3)	32.0 (0.4)	2.0 (0.4)
4-6	6	65.5 (0.3)	31.9 (0.7)	1.7 (0.2)
6-8	5	65.6 (0.3)	31.3 (1.0)	1.2 (0.7)
8-10	4	65.7 (0.2)	31.7 (0.4)	1.6 (0.2)

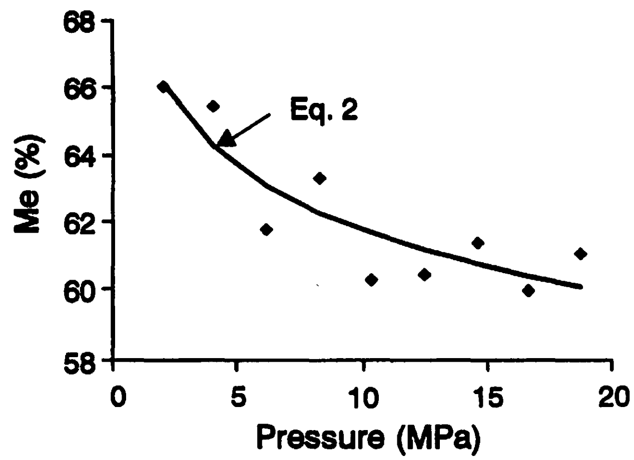

Fig. 2. Equilibrium moisture content of the pressed pulp vs the applied pressure.

Equation 1 predicted a lower moisture content for the pressed pulp than the experimental value of the present study. This might have been due to excessive maceration of alfalfa samples by Koegel and Bruhn (1972). Data in Table I yielded:

$$Me = 68.4 P^{-0.0442} \qquad (2)$$

The regression coefficient for the linearized form of Eq. 2 (logarithmic transformation) was $R^2 = 0.79$. Figure 2 shows the plot of Eq. 2 and the experimental data.

Increasing pressure tests

Table II lists the pressure ranges and the number of samples for each pressure treatment. For fresh alfalfa, two samples (65 g each) yielded 20.8 g of juice each. For subsequent pressures, the yield of juice from pre-dewatered pressed pulp was small, ranging from 1.2 to 2.0 g. Four to six repetitions were needed to collect a quantity of juice adequate for analysis.

An exponential relation for the ratio of pressure/moisture gradient ($\Delta P/\Delta M$) vs the initial moisture content of the pulp was fitted to the data in Table II:

$$\frac{\Delta P}{\Delta M} = 7.592 \exp(-0.2279\, Mo) \qquad (3)$$

where Mo = initial moisture content of the pulp (%wb). The units for ΔP and ΔM are MPa and %wb, respectively. The regression coefficient for estimation (logarithmic transformation) is 0.94. Figure 3 shows the plot of Eq. 3 along with the experimental data. The equation is extrapolated and plotted to the left of the data. The curve shows an exponential increase in pressures required to reduce moisture content at lower levels of remaining moisture in the plant material.

Table III lists the data for moisture content, protein content, and β-carotene content from series three. Fresh alfalfa at 75.7% moisture had 20.6% crude protein and 18.9 mg/kg (31473 international units, IU/kg) of β-carotene. The first compression stage (0-2 MPa) reduced the moisture content of the fresh alfalfa to 68.3% m.c. The second compression range (2-4 MPa) reduced the moisture content of the pressed pulp to 65.9% m.c. Finally, the fifth compression range (8-10 MPa) reduced the moisture content of the pressed pulp to 63.8%. The total drop in moisture content during five stages of compression was 11.9% points.

Crude protein content of the pulp varied from approximately 22.2 to 24.3% on a dry mass basis (db). The protein content in the juice varied from 14.2 to 18.1% (db) indicating that much of the protein remained in the pulp. The β-carotene content in the pulp (26.4-33.6%) was also higher than that in the juice. The highest β-carotene content in the juice was extracted at the compression range of 0 to 2 MPa. β-carotene content of the juice extracted at the compression range of 8-10 MPa was 9.8 mg/kg, indicating that most of the β-carotene had been leached out of the plant material at a lower pressure.

DISCUSSION

Previously published research, as well as the results of the present work on alfalfa juice extraction, revealed several important points. The degree of maceration prior to pressing has a large effect on the quantity and quality of juice extracted. Double-maceration increased the amount of charged material in the cylinder from 60 to 65 g. The fluctuations in the moisture content of the pressed pulp were higher in single-macerated chops than the double-macerated chops. Pressures up to 4 to 6 MPa reduced the moisture content of the fresh alfalfa from 75.7 to 60-65%. Higher pressures did not increase the yield of juice. Dry matter content of the juice was in the range of 10 to 12%.

Table III. **Analysis of pressed pulp and juice expressed at various pressure ranges in series three tests. Fresh alfalfa moisture content, 75.7%; crude protein content, 20.6%; β-carotene, 18.9 mg/kg (31500IU/kg).**

Stage no.	Pressure range (MPa)	Pulp m.c. (% wb)	Pulp crude protein (%)	Pulp β-carotene (mg/kg)	Juice dry matter (%)	Juice protein (%)	Jiuce β-carotene (mg/kg)
1	0-2	68.3	23.1	32.1	12.0	18.1	27.6
2	2-4	65.9	24.3	30.6	10.5	15.6	21.5
3	4-6	65.0	22.2	33.7	10.5	14.2	21.7
4	6-8	64.4	22.4	26.4	10.4	14.9	9.7
5	8-10	63.8	23.7	29.4	10.4	15.3	9.8

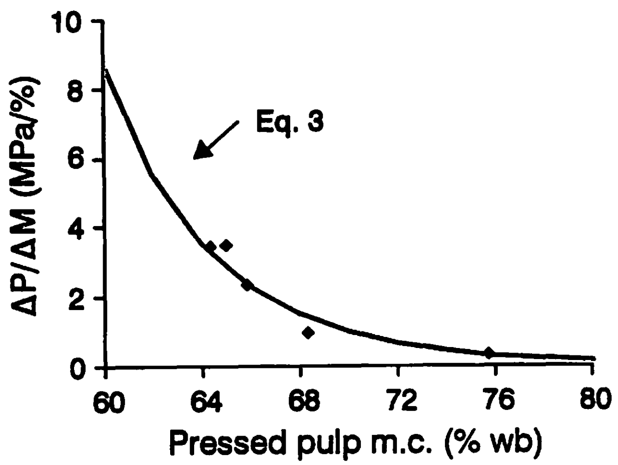

Fig. 3. Pressure/moisture content gradient vs moisture content of the pressed pulp.

The present work, however, has several shortcomings that should be considered in the planning of future experiments.

1. The alfalfa chops were frozen at –20°C for storage. The samples were then thawed prior to a pressure test. The freezing and thawing cycle might have affected the state of the water in the cellular structure of the plant material. It is important to repeat the tests with fresh chops without freezing.
2. All tests were done on one sample of field-cut alfalfa chops at a moisture content of 75.7% (wb). Future tests should be performed on larger samples of wider initial moisture contents.
3. The degree of maceration prior to pressing was difficult to quantify, yet maceration had a large effect on mechanical dewatering. A method should be developed to quantify the degree of maceration. Kraus et al. (1997) proposed an electrical conductivity probe for quantifying level of forage conditioning.
4. Unfortunately, we did not record either the rate of travel for the piston or compression ratios. These data are important for scale up designs.

This research showed that maceration is an important factor to the mechanical dewatering of alfalfa. It also showed that with pressures just greater than 4 MPa, more than 50% of the water content of the alfalfa can be removed.

CONCLUSIONS

1. Double maceration of alfalfa chops increased the amount of charged fresh alfalfa in the cylinder housing; it also reduced fluctuations in the yield of pressed pulp and juice.
2. About 52% of the juice mass was extracted by applying pressures greater than 4 MPa. The amount of pressure required to extract a unit of moisture increased exponentially with decreasing available moisture in the pre-dewatered pulp.
3. The juice had a minimum of 10% dry matter content.
4. On a dry matter basis, the contents of protein or β-carotene in the pulp did not decrease as compared to these contents in fresh alfalfa.

ACKNOWLEDGMENTS

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