PRO-XAN Process: Incorporation and Evaluation of Sugar Cane Rolls in Wet Fractionation of Alfalfa

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Sugar cane rolls have been shown to be effective for fractionating freshly harvested alfalfa in pilot plant as well as commercial scale operations in which 20 to 40 tons per hr were processed. One rolling removed 15 to 20% of the solids and 25 to 30% of the protein. Three rollings removed a third of the solids and almost half of the protein originally present. The expressed juice is also high in carotene and xanthophyll, and can be processed into a good quality poultry feed supplement. Added ammonia was effective in reducing xanthophyll loss during the processing and in protecting the chlorophyll from degradation. The pressed cake which remains after rolling can be dried on conventional commercial dehydration equipment and still meets the standards for good quality dehydrated alfalfa meal.

It is well known that leafy plants can be used to yield considerable amounts of protein (Bickoff *et al.*, 1947; Chayen *et al.*, 1961; Pirie, 1952, 1957a, b). The urgent need to find new sources which are of sufficiently high nutritive quality to be used as a dietary supplement to help relieve the world's protein malnutritional problem has resulted in an increased interest in the fractionation of green, leafy materials such as alfalfa (Akeson and Stahmann, 1965; Gerloff *et al.*, 1965; Kinsella, 1970; Pirie, 1969). Although there have been several attempts to commercialize the preparation of leaf protein concentrates (*Chem. Ind.*, 1959; *Farm Mechanization*, 1952; *World Crops*, 1953), they have so far been unsuccessful for several reasons. At present the protein cannot be economically produced for either human or animal use unless other valuable products are concomitantly produced to help pay the processing cost. Development of leaf protein for human use has been hindered by its green color and off-flavor. Yields of protein have been relatively low, and markets would have to be developed for a low protein residue. Furthermore, large scale equipment specifically designed for maximum protein recovery from leaves is not commercially available.

The development of high energy poultry rations has been reducing the market for high fiber products such as dehydrated alfalfa meal. A large potential market exists for a low fiber, high-xanthophyll supplement for broilers and laying hens which can be fulfilled by leaf protein concentrate. The green color of the chlorophyll will enhance rather than detract from the market value of the product for chick feed. The wet fractionation technique, developed at our laboratory for the production of such a high xanthophyll, high protein, low fiber concentrate (Kohler *et al.*, 1968; Spencer *et al.*, 1970), has been named the PRO-XAN Process. This process, which involves the mechanical expression of a portion of the liquid from fresh alfalfa, yields a green juice essentially free of fiber and leaves a high-quality pressed cake still suitable for animal feeds. Dehydrated alfalfa meal can be prepared from the pressed cake to meet the present market grades. Wet fractionation is easily incorporated into a conventional dehydrated alfalfa meal production process. The leaf-protein concentrate is then a byproduct of an already established process, rather than the primary product. The prototype unit of this process has already been installed by a cooperating commercial dehydrator (Batley-Janss Enterprises, Brawley, Calif.) and is now undergoing commercial evaluation.

Machinery which has been used for leaf protein extraction can be divided into four classes, based on the method used for maceration, *i.e.*, screw expellers, rollers, moving knives, and hammer mills (Tilley and Raymond, 1957). The latter two require some type of press to express the juice from the pulp. More recently, Pirie has recommended the combination of a pulper (Davys and Pirie, 1960) and a belt press (Davys and Pirie, 1965; Pirie, 1969). For the scale needed for the specific commercial application we had in mind, machines capable of handling over 20 tons or more of fresh alfalfa per hr were required. Commercial sugar cane rolls (Goodall, 1936; Slade *et al.*, 1945) with standard groovings were found capable of handling the required throughput. These rolls can be fully automated and they simultaneously crush the material and express the juice. Smooth juicing rolls have been investigated (Kohler *et al.*, 1968) and are also satisfactory. However, smooth rolls would not be expected to feed as well as grooved rolls on low fiber lots of raw material. This paper reports the evaluation of laboratory-scale sugar cane rolls and other equipment in the pilot plant, as well as the preliminary evaluation of the application of commercial-scale sugar cane rolls to alfalfa.

EQUIPMENT

Laboratory. For laboratory experiments, a Norwalk Triturator, Model 200 (shredder-type action), equipped with a hydraulic press, was used for pulping the alfalfa and expressing the juice.

Pilot Plant. The pilot plant system is shown in Figure 1 and consists of the following components. The feeder "A" (Arnold Dryer Co. Model No. A632-44) is equipped with a bottom drag driven by a variable speed fractional hp motor.

The uplift conveyor "B" (Chisholm Ryder), 12 in. wide by 9 ft long, is equipped with a rubber belt which has 1.25-in. cleats spaced at 12-in. intervals. The belt is driven by a fractional hp motor equipped with a variable speed transmission. The angle of lift is 45°.

The leveling conveyor "C" is a smooth belt conveyor, 11.5 in. wide by 8 ft long, and is equipped with a leveling reel (paddle wheel type) and an 8 by 12 in. permanent magnet. The belt and reel are driven by fractional hp motors equipped with variable speed transmissions.

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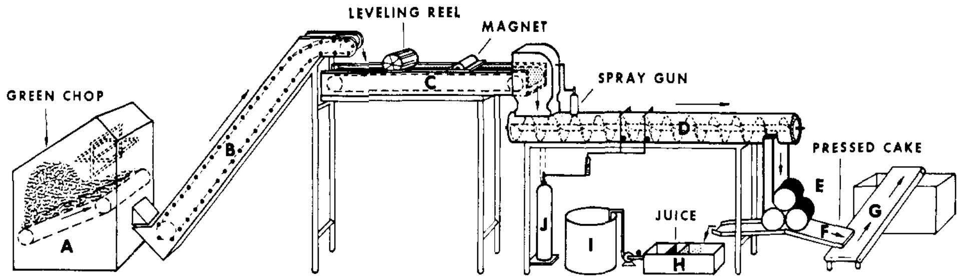

Figure 1. Pilot plant for expression of juice from alfalfa

An enclosed screw conveyor, "D" 11 in. in diameter and 9.75 ft long, is used to ammoniate the chopped alfalfa through two $^1/_4$ in. pipe fittings located on the top of the unit. It is powered by a 3 hp motor equipped with a variable speed transmission. A DeVilbis (type JFA) spray gun is attached.

The juicing rolls "E" are 12 in. long, 8 in. in diameter, and arranged in a triangular pitch (Figure 2). The gaps A and B (Figure 2) are 0.41 in. and 0.08 in., respectively. The rolls are powered by a 5 hp motor and operate at 5 rpm. They are fitted with a 5 by 11.5 by 28-in. feed chute, with a plastic window for viewing the alfalfa level.

The pressed cake discharge drag conveyor "F" is a bar-type, 9 by 16 in., equipped with round $^3/_8$ in. bars spaced at 8 in. intervals. The conveyor is driven by a variable speed motor.

The discharge conveyor belt "G," 1 by 10.5 ft, is a smooth belt driven by a constant speed motor.

The juice tank "H" is 11 by 30 by 12 in. deep and is fitted with three metal screens of different meshes for fiber removal. The screens are arranged according to size of openings which are, in sequence, 0.1 in. woven mesh, 0.1 in. perforated sheet, and 0.06 in. perforated sheet.

The commercial-scale rolls are 5 ft long and 2.5 ft in diameter, and are arranged as shown in Figure 2. These rolls are driven at 7 rpm by a 150 hp motor. The roll gaps were $1^3/_8$ in. for inlet and $^7/_8$ in. exit.

PROCEDURES

Freshly-harvested chopped alfalfa (supplied by Dixon Dryer Co., Dixon, Calif.) was metered by the feeder (Figure 1A) onto the uplift conveyor "B." This conveyor raised the alfalfa above the rolls to a height required to maintain maximum feed. The material was then carried on the leveling conveyor "C" past the leveling reel and the permanent magnet. The reel, rotating in a direction opposite to the belt, leveled the chopped material into a 1 in. mat which passed under the magnet for removal of stray ferrous metal objects and discharged into the screw conveyor "D." Aqueous solutions of ethoxyquin were sprayed onto the alfalfa at the screw conveyor inlet. This enclosed conveyor also permitted application of gaseous ammonia from ammonia cylinder "J" onto the alfalfa. The treated material was mixed as it was carried by the screw to the feed chute of the rolls "E." The feed was maintained at a depth of 15–20 in. in the feed chute for the best rolling efficiency by suitable adjustment of feed rate feeder "A." As the material passed through the rolls, it was compressed to about $^1/_5$ of its bulk volume, freeing the green juice. The juice, along with some fiber, was passed through the juice tank "H," where the fiber was removed by the screens. The juice was then pumped to a holding tank "I" for further processing. The pressed cake was scraped from the discharge side of the rolls by doctor blades and removed by the press cake discharge conveyor "F." Conveyor "G" moved the material from conveyor "F" to a holding bin for further processing or dehydration.

In a typical pilot plant run, the system was operated for 1 hr. During this time, at predetermined intervals, replicate samples (1 to 2 pounds) of whole alfalfa, pressed cake, and green juice were collected by combining small portions taken over a 3- to 5-min period. The samples were collected at the following locations: the whole alfalfa, at the exit of the screw conveyor (Figure 1D); the pressed cake, at discharge conveyor "F"; and the juice, at juice tank "H." Each sample was quickly frozen in dry ice-acetone for freeze-drying. After freeze-drying, the samples were ground in a Wiley mill through a 20 mesh screen and stored in sealed containers at $-10°$ F until analyzed.

The aqueous ethoxyquin was added at a rate calculated to give 0.015% antioxidant on a dry weight basis. Gaseous ammonia was added at a flow rate sufficient to give the desired pH in the expressed alfalfa juice. Between 2 and 3 pounds of ammonia per ton of whole alfalfa was required for a pH of 8.5.

In the multiple rolling experiments, 100 pounds of pressed cake was withdrawn from the holding bin for re-rolling. It was hand fed onto the uplift conveyor "B." The pressed cake from the second rolling was hand mixed with water, equal in weight to the total weight of green juice removed by the first two rollings, and rolled a third time in a similar manner. The green juice from each rolling was collected separately. Samples were taken for analysis and handled as above.

ANALYTICAL METHODS

The methods used for sample analysis were as follows.

Moisture. The moisture content was determined by drying at 110° C for 2 hr in a forced draft oven.

Proximate Composition. Mineral, ether extractives, crude protein, and crude fiber were determined by the standard

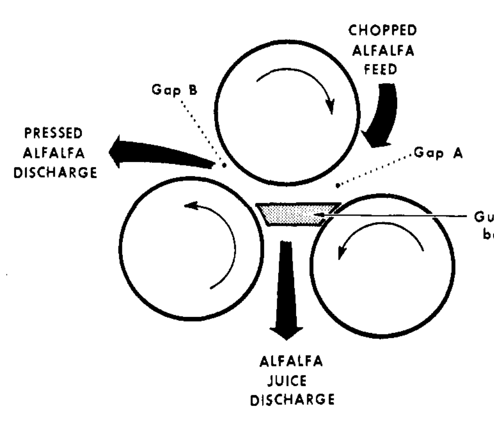

Figure 2. Arrangement of rolls

AOAC methods (Official Methods of Analysis, 1965). The term protein as used in this paper refers to crude protein (N × 6.25) and includes nonprotein nitrogen (X6.25) as well as coagulable "true protein."

Carotenoids. Carotenoid determinations on freeze-dried whole alfalfa and pressed cake were by the method of Kohler *et al.* (1967). The carotenoids in freeze-dried green juice were determined by the method of Quackenbush *et al.* (1970).

Calculation of Weight Distribution. The weight distribution was calculated by solving simultaneous equations representing moisture and solids of the pressed cake, green juice, and whole alfalfa. In this method, equations of solids and moisture contents were solved to give the weight of pressed cake or green juice from a given weight of alfalfa. The following is an example assuming the following data: whole alfalfa, 100 pounds, with 20% solids; pressed cake (C) with 25% solids; and green juice (J) with 8% solids.

$$\text{Solids:} \quad 0.20\,(100) = 0.25\,C + 0.08\,J$$
$$\text{Moisture:} \quad 0.80\,(100) = 0.75\,C + 0.92\,J$$

These equations were solved to give 70.56 pounds for the pressed cake (C) and 29.44 pounds for the green juice (J).

RESULTS AND DISCUSSION

The pilot plant rolls can process from 100 to 1000 pounds of fresh alfalfa per hr, depending upon the gap ratio (gaps A & B, Figure 2) and the characteristics of the material. A 5 to 1 ratio of the inlet gap A to exit gap B was found to produce a fair compromise between throughput rate and squeezing efficiency. This setting allowed a maximum throughput of 900 pounds per hr, which resulted in 35 to 50% of the weight of the fresh alfalfa being removed as green juice. This percentage was in agreement with earlier reports of juice yields by rolling (Slade *et al.*, 1945) and was one half to three quarters the yield obtained by a conveyor ram press (Pirie, 1959). As in the case of screw expellers (Casselman *et al.*, 1965), the weight of juice expressed was dependent upon the age as well as the moisture content of the fresh alfalfa. In our work, the juice yields also decreased with plant maturity (Table I). The solids content of the expressed juice was usually under 10%. On occasion, processing of mature alfalfa yielded juice containing as much as 12% solids. This decrease in juice yields was probably associated with the amount and toughness of fiber and with lower moisture content. As moisture content of the alfalfa decreased from 86 to 75%, juice yields decreased from 50 to 36 pounds per 100 pounds of fresh material. On an average, 40% of the weight of fresh alfalfa was expressed as a juice, which contained 7 to 12% solids. This represented a 15 to 20% removal of the solids present in the alfalfa.

Solids and protein yield can be increased by repeated pressing of the crushed alfalfa. McDonald (1954), using a roller press, reported that an additional 15% of the protein can be extracted in a second pressing. In comparison, a second pulping and conveyor pressing extracted an additional 25% of the protein (Morrison and Pirie, 1961). These workers added water to the crushed material before the second extraction. In our tests, multiple rollings also increased the percentage of solids and protein extracted (Table II). The first rolling of the chopped alfalfa (80% moisture) removed 19% of the total solids and 27% of the crude protein. Without adding water, a second rolling removed an additional 6% of the solids and 8% of the protein. When water was added prior to a third rolling, a combined total of 34% of the solids and 45% of the protein were removed in the three pressings. Although 45% of the protein was removed, the residual pressed cake still contained 19% protein (dry basis) and can still meet the requirements for high grade dehydrated alfalfa meal. This was because nonnitrogenous solids (*e.g.*, sugar, salts) were extracted along with the crude protein.

The solids composition of all the green juices and pressed cakes, prepared with or without added ammonia, were similar (Table III). Since N × 6.25 is employed for protein assay, the apparent increase in protein of the ammonia treated green juice would be expected from the small amount of ammonia added to the system. The carotenoid content of the pressed cake was similar to that of whole alfalfa (Table IV). After

Table I. Juice Yields Compared to Age and Condition

Condition	Age Days	Juice Yield Pound/100
Prebloom	15	48
Prebloom	20	43
1/10 Bloom	35	34
Full bloom	80	32

Table II. Distribution of Protein and Total Solids in Multiple Rolling of Alfalfa

Fraction	Percent of Total Solids	Percent of Total Protein	Percent Protein[a]
Whole alfalfa	100	100	23
First rolling			
Green juice	19	27	
Pressed cake	81	73	21
First, second rollings			
Green juice	25	35	
Pressed cake	75	65	20
First, second and third rollings			
Green juice	34	45	
Pressed cake	66	55	19

[a] Dry weight basis.

Table III. Composition[a] of Alfalfa, Expressed Juice, and Residue

Product	Protein %	Fiber %	Fat %	Ash %
Untreated				
Whole alfalfa	22.5	22.6	4.8	9.9
Pressed cake	20.4	28.2	4.5	7.7
Green juice	32.3	0.4	1.5	17.2
Ammonia treated				
Whole alfalfa	23.2	22.8	4.0	9.8
Pressed cake	20.7	27.9	4.5	8.0
Green juice	36.4	0.5	0.8	18.4

[a] Dry weight basis.

Table IV. Carotenoid Content Compared to Quality of Alfalfa

Product	Carotene[a] mg/lb	Xanthophyll[a] mg/lb
Poor quality		
Whole alfalfa	125	252
Pressed cake	122	242
Green juice	98	214
Good quality		
Whole alfalfa	160	365
Pressed cake	150	350
Green juice	130	307

[a] Dry weight basis.

Table V. Carotenoid Losses During Grinding and Rolling

Material	Carotene Loss Grinding %	Carotene Loss Rolling %	Xanthophyll Loss Grinding %	Xanthophyll Loss Rolling %
Untreated alfalfa	35	17	37	17
Ammonia treated to pH 8.5	19	8	12	8
Ethoxyquin treated	25	16	22	15
Ammonia + ethoxyquin treated	15	8	11	8

Table VI. Preliminary Evaluation of the Commercial Rolls

Material	Percent of Wet Weight	Carotene[a] mg/lb	Xanthophyll[a] mg/lb
Whole alfalfa	100	139	314
Pressed cake	70	132	302
Green juice	30	107	250
Loss during rolling (%)		6	6

[a] Dry weight basis.

rolling, 10 to 12% of the total carotenoids was in the juice and 80 to 85% was in the pressed cake. Possibly the 3 to 10% unaccounted for was lost during rolling.

Carotenoid losses occurring during the processing of fresh plant materials are due to enzymatic and oxidative reactions (Bernstein and Thompson, 1947; Booth, 1960; Bondi *et al.*, 1968). These losses in processing fresh alfalfa can be reduced by aqueous ammonia (Peebles *et al.*, 1951a,b; Kohler *et al.*, 1968) and antioxidants such as ethoxyquin (Knowles *et al.*, 1968).

The carotenoid loss, studied in the laboratory using a Norwalk Triturator, showed that 1/3 of the carotenoids were lost during grinding. These losses were reduced by the addition of ammonia or ethoxyquin before grinding (Table V). The ammonia stabilized the green color as well as the carotenoids. The carotenoid loss was less in rolling than in grinding. This difference was probably due to higher temperatures generated and greater maceration with increased lipoxidase action during grinding. Carotenoid retention during rolling also depended upon the initial temperature of the alfalfa being processed. Untreated alfalfa harvested on a frosty morning and roll pressed while partially frozen had less than 5% carotenoid loss, while comparable material processed on a warm summer day lost as much as 20%. During the rolling operation the carotenoid losses were not significantly reduced by ethoxyquin (Table V). As the result of these and other experiments, addition of ammonia was adopted as unit process in the PRO-XAN Process.

Preliminary evaluation of the commercial rolls has shown that their performance was similar to the pilot plant rolls (Table VI). The carotenoid losses, when ammonia was added prior to rolling, were similar to those obtained in the pilot plant (Tables IV and V). The commercial rolls were operated at a faster speed, resulting in a higher throughput but a slightly lower yield of juice. These preliminary trials have shown that the rolls are capable of handling 20 to 40 tons of fresh chopped alfalfa per hr and of yielding a green juice flow in excess of 2000 gal.

The concept of speeding up drying by crushing the plant goes back at least 25 years. Thompson (1952) reported that rolling alfalfa cracked the stems and reduced drying time. More recently, the decrease in drying time has also been attributed to the fact that crushing alfalfa not only splits the stems, but also breaks their waxy coat (Mears and Roberts, 1969). These factors, coupled with lower moisture content in the press cake, allow an increased feed rate through the dehydration unit (Spencer *et al.*, 1970). The extraction process described in this paper provides a raw material for the preparation of leaf protein, while at the same time permitting the industry to prepare a good quality dehydrated alfalfa meal. The whole juice can be spray-dried into a high xanthophyll-low fiber feed ingredient for nonruminants (Hartman *et al.*, 1967) or further processed into a concentrate of even higher protein and xanthophyll content (Kohler *et al.*, 1968).

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