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Developing Reuse Alternatives for Corn Masa Processing Byproduct Streams

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Abstract

Increasing production of corn masa for tortillas, chips, and related snack foods is resulting in large quantities of organic residuals requiring environmentally-sound management strategies. This study focused on developing value-added livestock feed from these processing byproducts. First, a complete physical and nutritional analysis was conducted. Laboratory-scale and pilot-scale extrusion trials were then performed. Finally, to assess the actual viability of a livestock feed material, an economic model was developed. Through a series of simulation runs with this model, it was determined that direct shipping was by far the most inexpensive means of recycling masa processing residuals as feed ingredients (10 to 57 $/Mg). Blending prior to shipping resulted in increased costs (3 to 15 times greater). Extrusion and pellet mill processing were considerably more expensive than direct shipping (5 to 18 times, and 4 to 18 times greater, respectively), while dehydration was clearly cost prohibitive (33 to 81 times greater). Based on this cost analysis, it is recommended that direct shipping and feeding to livestock be implemented as the recycling option of choice for masa processing byproducts. Although details of process configurations and costs will vary, similar results are likely for other high-moisture food processing residuals destined for utilization as livestock feed or components thereof.

Keywords

Byproduct utilization, extrusion, recycling, simulation, systems analysis

Disciplines

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Comments

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Abstract. *Increasing production of corn masa for tortillas, chips, and related snack foods is resulting in large quantities of organic residuals requiring environmentally-sound management strategies. This study focused on developing value-added livestock feed from these processing byproducts. First, a complete physical and nutritional analysis was conducted. Laboratory-scale and pilot-scale extrusion trials were then performed. Finally, to assess the actual viability of a livestock feed material, an economic model was developed. Through a series of simulation runs with this model, it was determined that direct shipping was by far the most inexpensive means of recycling masa processing residuals as feed ingredients (10 to 57 $/Mg). Blending prior to shipping resulted in increased costs (3 to 15 times greater). Extrusion and pellet mill processing were considerably more expensive than direct shipping (5 to 18 times, and 4 to 18 times greater, respectively), while dehydration was clearly cost prohibitive (33 to 81 times greater). Based on this cost analysis, it is recommended that direct shipping and feeding to livestock be implemented as the recycling option of choice for masa processing byproducts. Although details of process configurations and costs will vary, similar results are likely for other high-moisture food processing residuals destined for utilization as livestock feed or components thereof.*

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DEVELOPING REUSE ALTERNATIVES FOR CORN MASA PROCESSING BYPRODUCT STREAMS

Kurt A. Rosentrater, Thomas L. Richard, Carl J. Bern, and Rolando A. Flores

INTRODUCTION

Corn masa processing is one segment of the grain industry that generates large quantities of waste materials, but to date, has received little attention regarding byproduct disposal alternatives. Corn masa is used to produce corn tortillas and corn tortilla chips. Corn masa is produced by simulating, on an industrial-scale, the ancient Aztec art of lime-cooking corn. Whole corn is cooked with 120 to 300% water (original corn weight basis) and 0.1 to 2.0% lime (original corn weight basis) for 0.5 to 3.0 h at 80 to 100°C, and is then steeped for up to 24 h. This process, called "nixtamalization", can be either a batch process or a continuous process, depending on production equipment. The cooked grain (known as "nixtamal") is then separated from the steep liquor (called "nejayote"), which is rich in lime and corn pericarp tissues (which were loosened during cooking and steeping). The nixtamal is washed to remove any excess lime and pericarp, and is then stone ground to produce a dough called "masa". The masa is then molded, cut, or extruded, and then baked or fried to make tortillas, tortilla chips, or corn chips. The masa can also be dried and milled into masa flour, which can later be reconstituted and made into fresh tortillas at food service establishments (Rooney and Serna-Saldivar, 1987; Serna-Saldivar et al., 1990).

Nejayote, the steeping liquid byproduct, contains approximately 2% total (dissolved and suspended) solids. The total solids in the waste stream, which consist primarily of fiber-rich pericarp tissues, represent corn dry matter losses that occur during processing. Estimates of this original corn dry matter loss have ranged from 5% to 17%. Typically the suspended solids (50 to 60% of the total solids) are removed by screening, centrifugation, or decanting, and are then disposed of in landfills. The remaining water and dissolved solids are sent to municipal water facilities for treatment (Pflugfelder et al., 1988; Rooney and Serna-Saldivar, 1987; Serna-Saldivar et al., 1990).

A few studies have been conducted into alternative disposal options for masa byproduct streams. Gonzalez-Martinez (1984) investigated four biological treatment options for nejayote on a laboratory-scale, including activated sludge processing, anaerobic contact processing, submerged aerobic fixed-film cascade processing, and anaerobic packed-bed processing, and found that the activated sludge and anaerobic packed-bed reactors were effective treatment options for these waste waters. Pflugfelder et al. (1988) studied the composition of masa processing dry matter losses, and included these losses in a mass balance of the masa production system. Velasco-Martinez et al. (1997) investigated the suitability of implementing nejayote solids in poultry broiler diets, and found no differences in performance between control diets and diets utilizing nejayote solids.

Because masa processing byproducts show potential for incorporation into livestock rations, the objective of this investigation was to develop a value-added byproduct feed material. To accomplish this, the study was implemented in four phases. First, masa byproduct solids (i.e., suspended solids removed from masa processing waste water; Figure 1) were subjected to complete physical and nutritional characterization. Second, to investigate the applicability of extrusion processing for their potential utilization, these solids were extruded on a laboratory-scale. Third, these solids were subjected to pilot-scale extrusion. Fourth, a computer model was developed to simulate and assess the economics involved with the production of livestock feed ingredients using masa residual streams.

PHYSICAL AND NUTRITIONAL CHARACTERIZATION

Characterization Methodologies

The first objective of this study was to identify and quantify relevant physical and nutritional properties of typical corn masa processing residues. Byproduct samples were taken from both continuous-cook and batch-cook processing lines. Physical properties studied included moisture content, water activity, mass density, yield stress, pH, color, and drying behavior. Nutritional properties included protein, fat, ash, mineral composition, amino acid composition, and fiber content. Standard laboratory procedures were used determine property values (Rosentrater et al, 1999; Rosentrater, 2001).

Characterization Results and Discussion

Table 1 summarizes the findings from this portion of the study. Masa byproducts appear suitable for use as livestock feed materials, or components thereof. These byproducts are very high in moisture content; but dried, they are high in fiber (especially cellulose and hemicellulose), and would probably be best suited for ruminant diets. Additionally, when dried, these products have a substantial calcium content, thus there may also exist a potential for use as a calcium source in livestock rations. Further details for this phase of the study can be found in Rosentrater et al. (1999) and Rosentrater (2001).

LABORATORY-SCALE EXTRUSION

Extrusion Methodologies

The second objective of this study was to blend and extrude corn masa processing byproducts with soybean meal on a laboratory-scale, and investigate the effects of blend ratio, extrusion temperature, and extruder screw speed on extrusion processing variables and on final extrudate product physical and nutritional characteristics. Masa byproducts were blended with soybean meal at four levels (0%, 10%, 20% and 30%, wet basis), and were then extruded in a laboratory-scale extruder at screw speeds of 50 rpm (5.24 rad/s) and 100 rpm (10.47 rad/s) with extruder temperature profiles of 80-90-100 ºC and 100-110-120 ºC. The extruder used was a ¾-in (0.755-in [19.18-mm] inner barrel diameter [ID]), single-screw laboratory extruder (Model 2003, C.W. Brabender Instruments, Inc., South Hackensack, NJ; Figure 5.1), with a single-flight tapered screw (Model 05-00-035, C.W. Brabender Instruments, Inc., South Hackensack, NJ).

Extrusion Results and Discussion

All blends were amenable to extrusion at the processing conditions used in this study. Blend ratio affected processing and product properties very little, though; most effects were due to screw speed and processing temperature. Laboratory-scale extrusion of these blends produced extrudates with nutritional properties similar to those of the raw ingredient blends, but with improved protein digestibility, which was due to the effects of the extrusion processing's heat treatment. Because soybean meal was used as a blending agent, little product expansion occurred at the extruder die, primarily due to lack of starchy components in the blends. Extrusion processing produced extrudates with excellent durability, which is essential to retaining quality during transport and storage of pelleted feed ingredients. Additionally, the resulting products had low water absorption and solubility, which is also important for retention of product integrity during storage. During processing, the dough melt in the extruder behaved as a pseudoplastic material, which is typical of most food doughs, and required less torque to convey the dough as screw speed was increased. An additional drying step (which was not incorporated into this study) was required for the extruded products, to reduce moisture and water activity levels to acceptable ranges, in order to prevent microbial spoilage during storage. More details regarding this portion of the study can be found in Rosentrater (2001).

PILOT-SCALE EXTRUSION

Extrusion Methodologies

The third objective was to blend and extrude corn masa processing byproducts with soybean meal on a pilot-scale, and investigate the effects of blend ratio, extrusion temperature, and extruder screw speed on extrusion processing variables and on final extrudate product physical and nutritional characteristics. Masa byproducts were blended with soybean meal at three levels (0%, 10%, and 20%, wet basis), and were then extruded in a pilot-scale extruder at screw speeds of 206 rpm [21.6 rad/s] and 360 rpm [37.7 rad/s]. The extruder used was a single-screw pilot-scale extruder (Model X-20, Wenger Mfg. Inc., Sabetha, KS).

Extrusion Results and Discussion

All blends were amenable to extrusion processing at the conditions used in this study. Pilot-scale extrusion and drying of these blends produced extrudates that were dry and microbiologically stable. Further, blend ratio seemed to affect processing and product properties very little; most effects were due to changes in screw speed, which, in turn, affected processing temperature. As was observed for soybean meal blends at the laboratory-scale, little product expansion occurred at the extruder die exit, primarily due to lack of starchy components in the blends. Pilot-scale extrusion processing also produced extrudates with excellent durability, which is essential to retaining quality during transport and storage of pelleted feed ingredients. During processing, the dough melt in the extruder barrel required less force to convey the dough as screw speed increased, again consistent with the results from the laboratory-scale extrusion. More details on this stage of the study can be found in Rosentrater (2001).

ECONOMIC SIMULATION MODELING

Model Development

The purpose of this portion of the study was to develop a model to compare the costs of landfilling masa residues (the traditional disposal method) with the economics of producing value-added byproduct feed material using five unique reprocessing alternatives. The options incorporated into the model included direct shipping, blending, extrusion, pelleting, and dehydration. Recycling options that deserve investigation, but were not examined here, include composting, direct land application, incineration, biomass energy production, and use as a fermentation feedstock. Specifically, the objective of this economic model was to determine byproduct feed sales price ($/Mg) required for each option in order to reach the breakeven point each year of operation, and then to compare these results to the costs of landfilling ($/Mg). The intent in developing this model was to provide a tool to assist masa manufacturers in choosing the most appropriate disposal option for a given production facility.

To cover as broad a range as possible, the model directly utilized byproduct production rates. The model incorporated 10 possible byproduct generation rates (Mg/yr): 1,000; 2,500; 5,000; 10,000; 20,000; 30,000; 40,000; 50,000; 60,000; and 70,000. The blending, extrusion, and pelleting options, however, required the addition of a dry carrier material to facilitate the extrusion process. Soybean meal was used in this analysis because of its high protein value and common use in the feed industry. For the purposes of this model, soybean meal addition was based on a 30% masa byproduct / 70% soybean meal blend ratio. This mixture ratio was used because it utilized the greatest amount of byproduct, and would still be able to be processed via these operations. If an alternative blending agent was desired, however, this mixture ratio could be easily adjusted during operation of the model.

This model utilized both intrinsic and extrinsic (i.e., user-specified) variables. Intrinsic variables included the various disposal options (i.e., the five reprocessing options and landfilling), byproduct generation rate (Mg/yr) at the 10 levels discussed previously, and delivery distance (0 to 100 miles [161 km] by 10-mile [16-km] increments). User-specified variables included interest rate (-), electricity price ($/kW-h), gasoline price ($/L), blending agent price ($/Mg), and landfill tipping fee ($/Mg). Additionally, when using the model, the user could readily specify which disposal option to examine, and for the appropriate options, whether bulk or bagged feed was to be produced.

Within the model, for each waste disposal option, equipment and building facilities were sized to adequately meet processing requirements, and the costs to purchase, ship, install, and operate these were determined. Using a service life of 15 years (n=15), the model accounted for all annualized costs and benefits for each option. Annualized fixed costs included equipment, buildings, engineering, depreciation, overhead, taxes, etc. The model also accounted for annualized variable costs, such as electricity, gasoline, dryer fuel, labor, raw ingredients (blending agents), water, maintenance, etc. Annual benefits only included the sale of byproduct feed materials and the annualized salvage value of equipment and structures.

A general balance sheet was implemented within the model to account for all annualized fixed and variable costs, as well as all annualized benefits, for each reprocessing option, as well as for landfilling. By determining these values, the required byproduct feed sales price ($/Mg) needed for each reprocessing option to reach the annual breakeven point could then be determined via Equation 1:

$$\mathrm{BBSP} = \frac{\sum \mathrm{AFC} + \sum \mathrm{AVC} - \sum \mathrm{AB}}{\mathrm{AMBP}} \quad (1)$$

where BBSP is the byproduct breakeven sales price ($/Mg), AFC is the annualized fixed costs ($/yr), AVC is the annualized variable costs ($/yr), AB is the annualized benefits ($/yr), and AMBP is the annual masa byproduct production rate (Mg/yr).

For the landfilling case, however, the only annualized benefit was salvage value, because the byproducts are not sold as feed materials. Consequently, total annualized costs to landfill were determined (i.e., breakeven never occurs for the landfilling scenario).

This portion of the study entailed a series of simulation runs with the model. Values of the five user-specified variables were chosen based on values representative of those found in the central United States during the summer of 2000. Values chosen included an interest rate of 9.50% (Federal Reserve, 2000; HSH Associates, 2000), an electricity price of 0.07 $/kW-h (EIA, 2000b; EIA, 2000c), a gasoline price of 1.50 $/gal (0.40 $/L) (EIA, 2000a), a soybean meal price of 150.00 $/ton (165.35 $/Mg) (TFC, 2000), and a tipping fee of 50.00 $/ton (55.12 $/Mg) (Ackerman, 1997; Goldstein, 1992; Johnson and Carlson, 1991; Jones, 1992).

Simulation Results and Discussion

Landfilling results are shown in Figure 2. As the results show, breakeven will never occur for the landfilling option. This is because the only annualized benefit derived from this process is the annualized salvage value from equipment and facilities (i.e., the byproduct is never sold). Additionally, the results show that as delivery distance (i.e., distance to the landfill) increases, the total cost for landfilling ($/Mg) increases slightly, which occurs due to increased gasoline consumption and labor costs associated with transporting the byproduct. As generation rate increases, for a given delivery distance, however, the total cost to landfill decreases, because economies of scale are achieved at the higher production rates. This occurs because production costs and capital investments vis-à-vis byproduct output are comparatively lower (McConnell, 1987). Because the costs associated with landfilling are usually considered "avoided" costs, the breakeven sales price calculated for all the other recycling options could, in fact, potentially be reduced to this amount and still be considered economically feasible.

Direct shipping in this model entails a processing line identical to that of the landfilling option. The only difference between these options is the final destination for the byproduct (i.e., landfill or livestock feeding facility). Of all reprocessing options in this study, direct shipping resulted in the lowest sales price required to reach breakeven (i.e., this was the most economical option for any masa production facility, because capital investment and production costs were minimized). These results are shown in Figure 2. As the results show, the required sales price slightly increased as delivery distance increased, but drastically decreased as byproduct generation rate increased (i.e., economies of scale occurred). "Ripples", however, can also be seen in the graph; these are actually due to the competing effects of economics of scale and "diseconomies of scale", which occur due to increases in equipment costs at increased production rates.

The blending and shipping option results (Figure 3) show behavior similar to direct shipping, but the levels of required sales price are considerably higher, due to the higher equipment investments, energy consumption, and costs associated with the acquisition and addition of a blending agent. Required sales prices are between 3 and 15 (with an average of 10) times greater than those of direct shipping alone. Diseconomies of scale can also be seen in the graph, primarily due to increasing equipment costs at greater production rates.

Extrusion processing, as Figure 3 shows, exhibits behavior similar to the previous options (slightly increased costs as delivery distance increases and drastically decreased costs as byproduct generation rate increases). Additionally, a few diseconomies of scale can be seen. The majority of behavior, however, can be attributed to economies of scale being achieved, and thus lower production costs as byproduct generation rate increases. Due to the equipment-intensive nature of this processing option, however, production costs are considerably greater than the direct delivery option. Extrusion processing, with the bagged feed option, has production costs 5 to 18 (with an average of 12) times those of direct shipping alone. Extrusion processing with the bulk feed option has production costs between 5 and 17 (with an average of 11) times the cost of direct shipping alone. The results also indicate that bagged feed has production costs 1.1 times greater than the bulk feed option. This is due to increased capital expenditures for bagging equipment and the associated energy costs to operate these machines. Because the costs associated with extrusion processing are so high, it appears that this reprocessing option may be cost-prohibitive, especially because the marginal nutritional gain resulting from this process is relatively small compared to the inherent composition of raw soybean meal (i.e., the masa byproduct slurries alter the nutrient content minimally, due to their high moisture content) (Rosentrater, 2001).

Pellet mill processing is also very process-intensive. In fact, this option is very similar to extrusion processing vis-à-vis equipment required. The simulation results for this option also reflect the trends shown by all previous options, as shown in Figure 3. The graph also shows both economies of scale being achieved, and slight diseconomies of scale that occur. Pellet mill processing, with the bagged feed option, has production costs 5 to 18 (with an average of 12) times that of direct shipping alone, while pellet mill processing with the bulk feed option incurs production costs 4 to 16 (with an average of 11) times those of direct shipping. As with the extrusion processing option, bagged feed is 1.1 times more expensive to produce than bulk feed. Although pellet mill processing is slightly less expensive than extrusion processing, it appears that this reprocessing option is also cost-prohibitive compared to direct shipping of the masa byproduct stream.

Dehydration, or drying, was by far the most expensive reprocessing option studied. Although this option was not as equipment-intensive as either extrusion processing or pellet mill processing, the major cost factor associated with this option was the amount of dryer fuel required to dry the wet byproduct slurry. Compared to direct shipping, drying with the bagged feed option incurred production costs 46 to 81 (with an average of 60) times greater, while drying with the bulk feed option had costs 33 to 79 (with an average of 55) times greater, respectively. (As with the extrusion and pellet mill processing options, bagged feed was 1.1 times more expensive to produce than bulk feed.) Thus, it appears that dehydration is not an economical choice for the recycling of corn masa byproducts. These results, in fact, were so high, compared to all other reprocessing options, that they were not plotted in Figure 3, because they would have adversely affected the readability of the graph. Although not shown graphically, the dehydration results exhibited similar trends vis-à-vis generation rate and delivery distance as all other reprocessing options studied.

SUMMARY AND CONCLUSIONS

Through this study it was found that masa byproducts (suspended solids removed from masa processing waste water) appear suitable for use as livestock feed ingredients, or components thereof. These byproducts are very high in moisture content, but when dried, they are high in fiber (especially cellulose and hemicellulose), and would thus probably be best suited for ruminant diets.

It was found that laboratory-scale extrusion of masa byproduct / soybean meal blends produced extrudates with nutritional properties similar to those of the raw ingredient blends, with improved protein digestibility due to the effects of the extrusion processing. Because soybean meal was used as a blending agent, though, little product expansion occurred at the extruder die, which was primarily due to lack of starchy components in the blends. Further, it was found that most effects on processing and product properties were due to extruder screw speed and temperature, not blend ratio.

It was found that pilot-scale extrusion and drying of masa byproduct / soybean meal blends produced dry and microbiologically stable extrudates with nutritional properties similar to those of the raw ingredient blends. As was observed for soybean meal blends at the laboratory-scale, little product expansion occurred at the extruder die exit, which was primarily due to lack of starchy components in the blends. Pilot-scale extrusion processing also produced extrudates with excellent durability, which is essential to retaining quality during transport and storage of pelleted feed ingredients. Further, blend ratio seemed to affect processing and product properties very little; most effects were due to changes in screw speed, which in turn affected processing temperature

Finally, by modeling the economics of reprocessing corn masa byproducts, it was found that direct shipping of masa byproducts was by far the most economical choice for the corn masa manufacturer. Blending masa byproducts was a more expensive recycling option, but still may be economically feasible, depending on the cost of the blending agent used. Extrusion processing and pellet mill processing were substantially more expensive, and thus were cost-prohibitive. Further, dehydration was far too expensive to justify economically.

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Table 1. Physical and nutritional properties of corn masa byproducts.

		Batch Process		Continuous Process	
Property	Sample Size (n)	Mean	C.V. (%)	Mean	C.V. (%)
Moisture Content (%, w.b.) †	25	89.29	0.68	88.15	1.13
Water Activity (-) †	25	1.00	0.32	0.99	0.12
Density (kg/m^3) †	25	1030.85	1.23	1047.32	1.25
Yield Stress (N/m^2) †	25	1618.08	9.99	1440.04	19.69
pH (-)	25	6.30	2.12	6.17	9.35
Color: Hunter *L* Value (-) †	25	49.13	4.96	35.15	6.25
Color: Hunter *a* Value (-) †	25	0.27	16.34	0.98	24.39
Color: Hunter *b* Value (-) †	25	9.38	11.63	6.85	7.15
Protein (%, d.b.)	10	4.76	8.71	4.90	7.29
Fat (%, d.b.) †	10	0.74	15.66	5.76	21.35
Ash (%, d.b.)	10	19.09	10.11	17.41	18.36
Carbohydrate (%, d.b.) †	10	75.41	2.30	71.93	3.18
NDF (%, d.b.) *	15	54.97	4.73	53.32	3.69
ADF (%, d.b.) ‡	15	30.91	9.93	32.50	2.81
Lignin (%, d.b.) †	15	0.36	68.07	0.67	55.89
Calcium (%, d.b.)	2	-----	-----	4.68	17.39
Potassium (%, d.b.)	2	-----	-----	0.07	15.43
Magnesium (%, d.b.)	2	-----	-----	0.13	13.14
Phosphorous (%, d.b.)	2	-----	-----	0.57	9.68

† denotes a significant difference between batch- and continuous-process means at the 0.05 level
* NDF: "Neutral Detergent Fiber"
‡ ADF: "Acid Detergent Fiber"

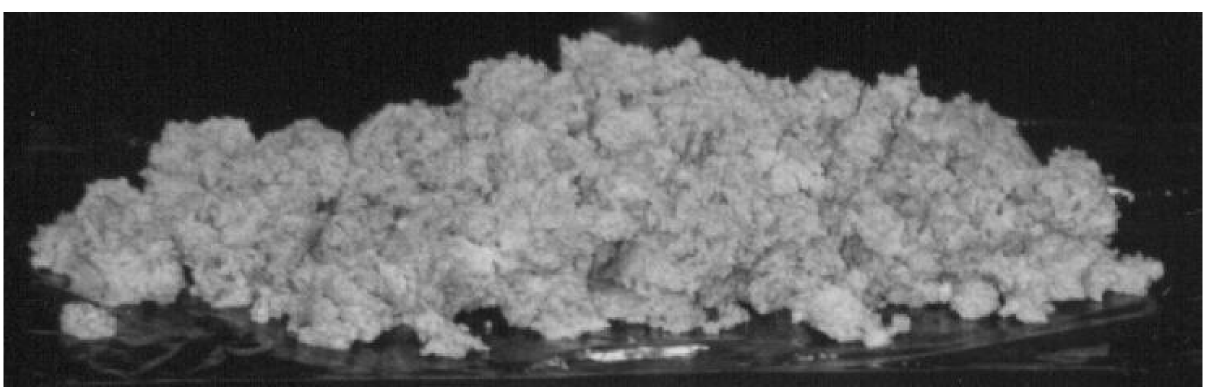

Figure 1. Typical corn masa processing byproduct residues.

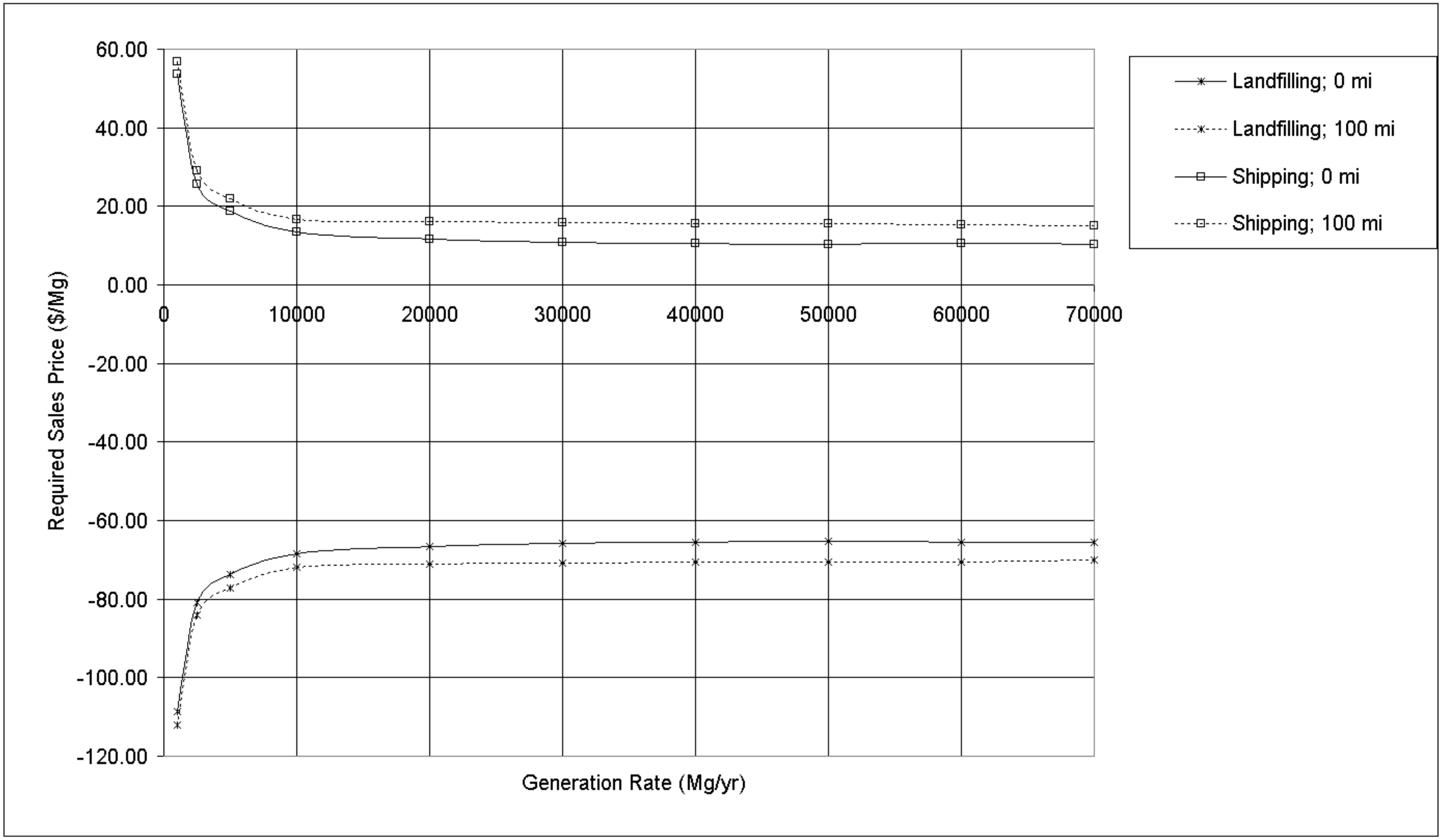

Figure 2. Effect of byproduct generation rate and delivery distance on byproduct sales price for landfilling and direct shipping.

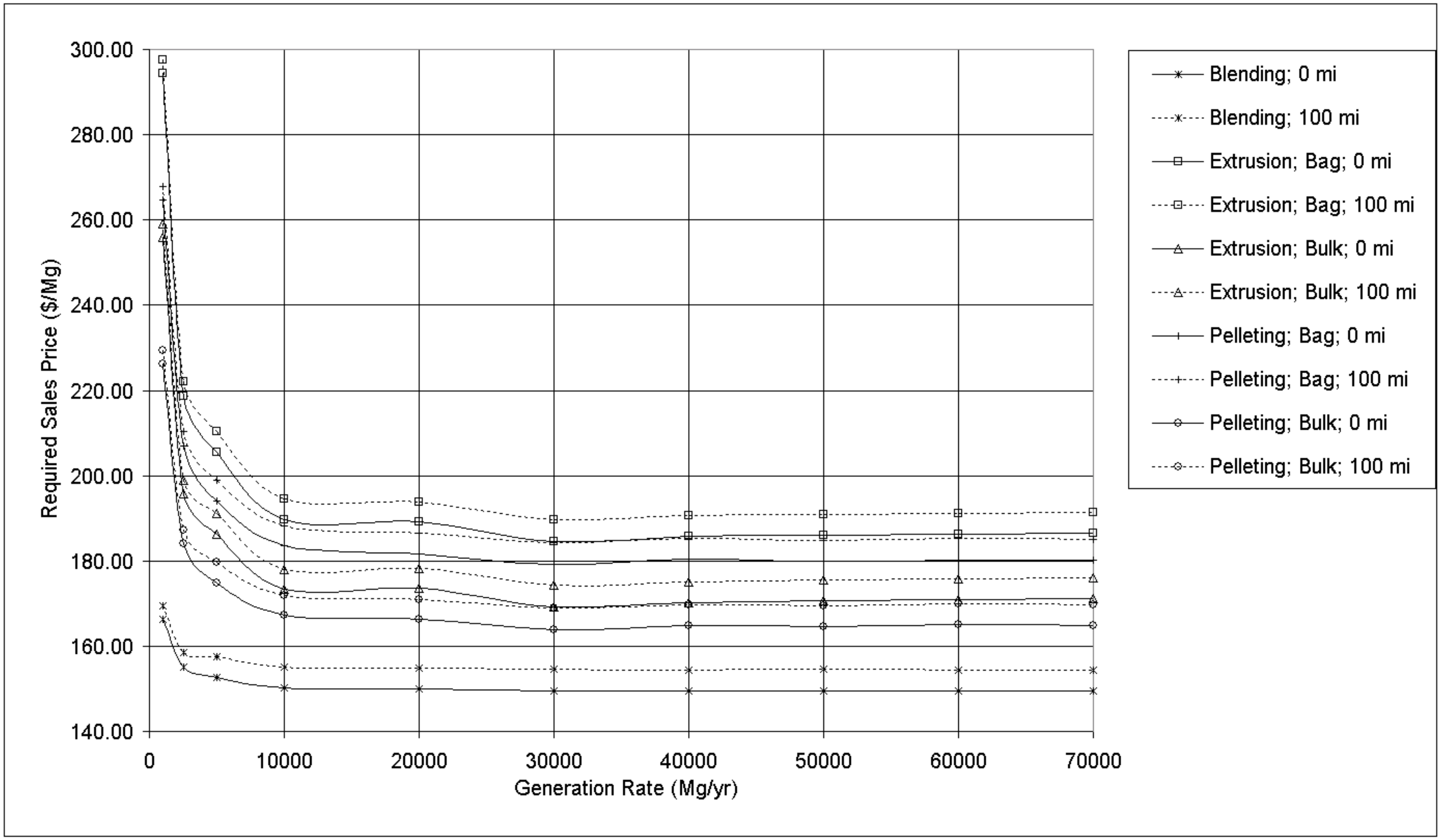

Figure 3. Effect of byproduct generation rate and delivery distance on byproduct sales price for blending, extrusion, and pelleting.