Optimal Production Planning of Concentrated Apple and Pear Juice Plants

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Abstract. This paper presents a mathematical model aimed at optimizing the yearly profit of a concentrated apple and pear juice plant through the appropriate design of its production plan. This study assumes a business scenario where the products are devoted to the international market and therefore the production schedule is dictated by a fluctuating prices scenario due to the worldwide supply/demand tradeoff. Moreover, raw fruit is available only during the relatively short harvest season and suffers juice yield reduction during storage. In this context, decisions related to the manufacturing of each juice variety to exploit favorable prices, while minimizing juice yield loss due to fruit aging are not intuitive. Scenario studies, together with sensitivity analysis on some model parameters are developed to illustrate the performance of the proposed approach.

Keywords: Concentrated Juice, Apple and Pear, Production Planning, Optimization Model

1 Introduction

Concentrated fruit juice became popular from the beginning of the forties due to the inherent advantages of reduced packaging, storage, and transportation costs. For the pome fruit case (apples and pears), large volumes of diluted juice are processed into a 70-75° Brix concentrates, which are very stable products that can be shipped and stored throughout the world in reduced volumes.

The concentrated pome fruit juice production process roughly involves the following steps: fruit washing, fruit crushing, pulp-pomace separation, pulp maceration, extraction, evaporation, centrifugation, filtration, concentration, packing and cold storage. For a detailed description of the process see Lozano [1]. Modern concentrated pome fruit juice industrial plants use similar technologies worldwide. Additionally, pear and apple juice can be produced in the same process units, with minimal adjustments required. These similarities in the processes and technologies enable conclusions drawn from particular case studies to be relevant to other plants worldwide. In this context, this work addresses a typical apple and pear concentrated juice plant in Argentina.

The largest part of apples and pears production in Argentina takes place in the "Alto Valle" region. About 38% of the apple production (236,215 tons) and 26% of the pear production (156,688 tons) were devoted to concentrated juice manufacturing in 2010 [2]. Typical juice plants in Argentina produce 72 Brix degrees clarified juice which is mostly used as a sweetening in the food industry. About 95% of the Argentine production is devoted to the international market.

The pome fruit juice production business faces an uncertain scenario regarding availability, quality, and cost of the fresh fruit due to the seasonal variations in weather conditions. Moreover, fluctuations in price and demand of the finished products are typical in the last years, due to an increased supply of worldwide juice as a consequence of the burst of the Chinese production into the global market. This situation increased the pressure on Argentinean manufacturers to become competitive and pursue a high quality product.

During the apples and pears harvest season, which in the south hemisphere takes place from January to May, the fruit arrives each day to the plant, where it is stored in the open until selected to be processed. Due to ripening processes, stored fruit undergoes a decrease in juice yield with time. For single processing line plants, while one of the species is under processing (e.g. apple), the other (pear) must remain stored suffering juice yield reduction. Therefore a tradeoff arises between the economical convenience of producing one of the products (e.g. apple juice) and the loss of opportunity of producing the other (pear juice).

In the past, juice plants used to operate at full capacity during the harvest season in order to transform all the received fruit into juice as soon as possible, minimizing therefore the juice yield loss. However, this strategy enforced that large amounts of product had to be either quickly sold (reducing the negotiation capacity of the company), or cold stored (increasing its operative costs). Moreover, with such strategy, the production facilities remained idle during a large part of the year and special seasonal labor arrangements were required. The described scenario motivated the companies to redesign their business strategy and to look into ways of increasing the operational flexibility of the plants and improve the overall production efficiency.

A key element in this process is to distribute juice production throughout the whole year. This is achieved by installing large pools where an intermediate product (turbid juice) can be stored for later processing. Usually, it is far convenient to store and later process turbid juice rather than directly producing concentrated juice which has to be specially packed and cold stored. Moreover, the low storage cost and stability of the turbid juice, allow to the companies to optimize the tradeoff between investment in infrastructure and increased annual production. Another improvement that increased the operational flexibility of the process was the inclusion of parallel units of the batch steps, which allowed operating the plant in a practically continuous fashion.

In this context of fluctuating costs and prices, fruit quality loss with time and flexible production capabilities a challenging production planning problem arises, aimed at deciding which product to manufacture each day of the working horizon in order to maximize the total profit of the firm throughout the business cycle.

The operational optimization of the apple juice production process has been previously addressed [3-4]. Moreover, some scheduling models applied to juice factories have been also reported [5]. However, according to the authors' knowledge, no optimal production planning studies on pome fruit juice plants, including storage fruit quality loss and price forecasts have been reported in the open literature. In this contribution such a study is presented. The purpose of the model is basically to investigate potential production strategies and identify bottlenecks rather than to define the production schedule of a whole year.

The proposed planning model adopts a multi-period approach, which spans a one year business cycle with daily resolution. Provided juice price forecasts and estimations of fresh fruit availability and production costs, the model calculates the specific periods when apple juice and pear juice have to be manufactured, aimed at optimizing the total profit of the industrial activity while considering the juice-to-fruit-ratio reduction with time. The adopted case study represents a typical pome fruit juice production plant located in the "Alto Valle" region in Argentina, whose production is fully devoted to the international market.

2 Mathematical model

The proposed mathematical model is based on the flow diagram of the pome fruit juice production process shown in Fig. 1. The first step is the fruit reception, where fresh fruit is stored in open vats or bins until processing. Process section P1 corresponds to the turbid juice production, involving the following operation steps: fruit washing, crushing, juice extraction and pulp-pomace separation. Process section P2 is the clarification and concentration section, involving pulp maceration, extraction, evaporation, centrifugation, filtration, concentration and packing. The apple and pear pools are large recipients to store turbid juice until clarification is performed. Finally, the cold storage stage consists of refrigeration chambers where the concentrated juice is stored until dispatch.

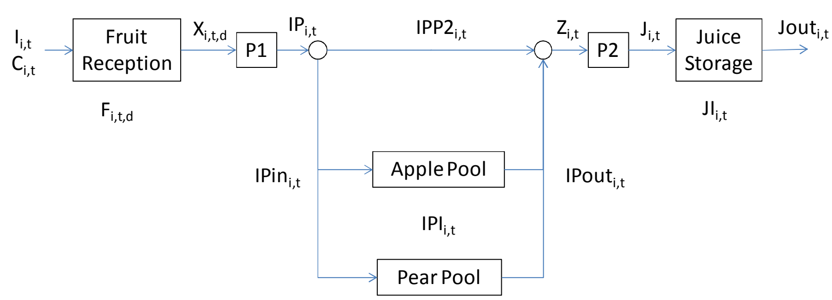


Fig. 1. Pome fruit juice plant process flowsheet

The problem addressed in this work considers a fruit juice plant that produces two products (i = pear, apple) over a planning horizon of one year, divided into t = 1, 2,..., 365 time periods of one day duration. In order to differentiate the time period when the fresh fruit *i* is processed, *t*, from that when it enters the system, the subscript *d* is included in the formulation. In other words, subscript *d* is used to monitor the daily fruit income along the harvest period while subscript *t* is used for indicating when the fruit is withdrawn from storage to be processed. Both situations are distinguished because a particular fruit batch can be processed in a day different than that it entered the system and even beyond the harvest season.

As was already mentioned, fruit kept in storage experiences juice extraction loss with time. Therefore, the concept of age (index *e*) is adopted to account for the storage period in the reception site, i.e. the number of time periods that fruit *i* is stored before it is processed ($e = 1, 2, \dots, 60$). Following, a Mixed Integer Linear Programming (MILP) mathematical formulation to solve the production planning problem of the pome fruit juice production process is described.

Fruit balance in reception site

$$F_{i,t,d} = I_{i,d} + C_{i,d} - X_{i,t,d} \qquad \forall\ i\ ,\ t = d \qquad (1)$$

$$F_{i,t,d} = F_{i,t-1,d} - X_{i,t,d} \qquad \forall\ i\ ,\ t > d \qquad (2)$$

$$X_{i,t,d} = 0 \qquad \forall\ i\ ,\ t < d \qquad (3)$$

$$\sum_i \sum_d F_{i,t,d} \leq FMAX \qquad \forall\ t \qquad (4)$$

Fruit processing in process section P_1 (intermediate product manufacturing)

$$IP_{i,t} = \sum_e YIELD1_{i,e=1+t-d}\ X_{i,t,d} \qquad \forall\ i, t \qquad (5)$$

$$y1_t = \sum_i yf1_{i,t} \qquad \forall\ t \qquad (6)$$

$$y1_t \leq 1 \qquad \forall\ t \qquad (7)$$

$$\sum_d X_{i,t,d} \leq P1MAX_i\ yf1_{i,t} \qquad \forall\ i, t \qquad (8)$$

Intermediate product distribution

$$IP_{i,t} = IPin_{i,t} + IPP2_{i,t} \qquad \forall\ i, t \qquad (9)$$

Intermediate product balance in pools

$$IPI_{i,t} = IPI_{i,t-1} + IPin_{i,t} - IPout_{i,t} \qquad \forall\ i, t \qquad (10)$$

$$IPI_{i,t} \leq IPMAX_i \qquad \forall\ i\ ,\ t \qquad (11)$$

Intermediate product processing in section P_2

$$Z_{i,t} = IPP2_{i,t} + IPout_{i,t} \qquad \forall\ i, t \qquad (12)$$

$$Z_{i,t} \leq P2MAX_i\ yf2_{i,t} \qquad \forall\ i, t \qquad (13)$$

$$y2_t = \sum_i yf2_{i,t} \qquad \forall\ t \qquad (14)$$

$$y2_t \leq 1 \qquad \forall\ t \qquad (15)$$

Concentrated juice production, storage and dispatch

$$J_{i,t} = YIELD2_i\ Z_{i,t} \qquad \forall\ i, t \qquad (16)$$

$$JI_{i,t} = JI_{i,t-1} + J_{i,t} - Jout_{i,t} \qquad \forall\ i, t \qquad (17)$$

$$\sum_i JI_{i,t} \leq JIMAX \qquad \forall\ t \qquad (18)$$

$$Jout_{i,t} \leq SHIP_t \qquad \forall\ i, t \qquad (19)$$

Process start-up

$on1_t \leq 1 - y1_{t-1}$ $\quad \forall\, t$ (20)

$on1_t \geq y1_t - BM\, y1_{t-1}$ $\quad \forall\, t > 1$ (21)

$on1_t \leq y1_t + BM\, y1_{t-1}$ $\quad \forall\, t > 1$ (22)

$IP_{i,t} \leq P1MAX_i\,(1 - on1_t)$ $\quad \forall\, i, t$ (23)

$on2_t \leq 1 - y2_{t-1}$ $\quad \forall\, t$ (24)

$on2_t \geq y2_t - BM\, y2_{t-1}$ $\quad \forall\, t > 1$ (25)

$on2_t \leq y2_t + BM\, y2_{t-1}$ $\quad \forall\, t > 1$ (26)

$Z_{i,t} \leq P2MAX_i\,(1 - on2_t)$ $\quad \forall\, i, t$ (27)

Product switching

$sw1_t \leq y1_t$ $\quad \forall\, t$ (28)

$sw1_t \leq y1_{t-1}$ $\quad \forall\, i, t > 1$ (29)

$sw1_t \geq yf1_{i,t} - yf1_{i,t-1} - (1 - y1_{t-1})$ $\quad \forall\, i, t > 1$ (30)

$IP_{i,t} \leq P1MAX_i\,(1 - sw1_t)$ $\quad \forall\, i, t$ (31)

$sw2_t \leq y2_t$ $\quad \forall\, t$ (32)

$sw2_t \leq y2_{t-1}$ $\quad \forall\, i, t > 1$ (33)

$sw2_t \geq yf2_{i,t} - yf2_{i,t-1} - (1 - y2_{t-1})$ $\quad \forall\, i, t > 1$ (34)

$Z_{i,t} \leq P2MAX_i\,(1 - sw2_t)$ $\quad \forall\, i, t$ (35)

Sales income

$SI = \sum_t \sum_i PJ_{i,t}\, Jout_{i,t}$ (36)

Raw material costs

$RMC = \sum_t \sum i CRMI_i\, I_{i,t} + \sum_t \sum_i CRMC\, C_{i,t}$ (37)

Operative costs

$OC = \sum_t \sum_i CO_i\, Jout_{i,t}$ (38)

Objective function

$OF = SI - RMC - OC$ (39)

Eqs. (1) and (2) allow determining in time period *t,* the amount of fruit *i* received in day *d* in the reception site, $F_{i,t,d}$. Variable $F_{i,t,d}$ is the inventory in period *t* of fruit of variety *i* that entered the system in period *d*. Eq. (1) establishes that the incoming fruit *i* has two components, the fruit provided by specific producers, $I_{i,d}$, whose production is fully committed beforehand with the company to ensure a certain processing activity throughout the year, and additional (on spot) fruit acquisition, $C_{i,d}$, to complement the anticipated production. Eq. (1) also states that the fruit received each day has age one.

Eq. (2) allows the daily monitoring of the age of the stored fruit. The stock of fruit *i* received in day *d* at the end of time period *t*, $F_{i,t,d}$, is equal to the amount in storage at the end of the previous period, $F_{i,t-1,d}$, less the amount processed in section P1, $X_{i,t,d}$. Furthermore, the stocks of species *i* stored during period *t* cannot exceed the maximum available storage capacity FMAX (Eq. 4), which is considered infinite in this study.

Each day *t*, fruit of different ages, and therefore of different extraction yields, are processed in process section P1 (Eq. 5). Parameter $YIELD1_{i,e}$ models the juice production loss of fruit *i* as function of storage permanence (age). In general it is difficult to estimate this relationship since quality loss depends on several factors such as the condition of the harvested fruit, which, in turn is a result of the growing process (weather, irrigation, etc.), and the storage (ambient) conditions. In this work, a base case correlation is adopted (see Appendix A) and a sensitivity analysis is performed to analyze how the production schedule behaves to variations on this important parameter.

Eqs. (6) and (7) ensure that at most one species (apple or pear) is processed each day *t* in process section P1. Production constraints are based on binary variable $yf1_{i,t}$, which is equal to 1 if species *i* is processed in time period *t* and equal to 0 otherwise. In order to determine if process section P1 is in operation in time period *t*, variable $y1_t$ is used. By introducing Eq. (7) into the formulation, the continuous variable $y1_t$ behaves like a binary variable since it is bounded by binary variables in Eq. (6). In Eq. (8) the amount of fruit *i* processed in time period *t*, is constrained because of the limited production capacity of process section P1, $P1MAX_i$ (700 ton/day).

After fruit *i* is processed in section P1, Eq. (9) enforces that the intermediate product *i* in time period *t*, IP_{it} is either stored in pools, $IPin_{i,t}$, or further processed in processing stage P2, $IPP2_{i,t}$. Eq. (10) monitors the intermediate product inventory of product *i* at the end of time period *t* in the pools, $IPI_{i,t}$, which have a limited capacity $IPMAX_i$ = 3000 ton (Eq. (11)).

Eq. (12) poses that the intermediate product processed in section P2, $Z_{i,t}$, can come directly from section P1, $IPP2_{i,t}$, and from the corresponding pool, $IPout_{i,t}$. Process section P2 has a certain processing capacity, $P2MAX_i$, and at most one species *i* can be processed at a time. This production logic is modeled in Eqs. (13) - (15) with the aid of binary variable, $yf2_{i,t}$ which is equal to 1 if species *i* is processed in section P2 in time period *t* and is equal to 0 otherwise.

Eq. (16) establishes that in time period *t,* fruit juice *i* is produced ($J_{i,t}$), from the intermediate product, $Z_{i,t}$, with a certain yield $YIELD2_i$ (0.2 ton/ton). In Eq. (17) the amount of product *i* stored in cold facilities at the end of period *t*, $JI_{i,t}$, will depend on the stock in the previous period, $JI_{i,t-1}$, the production during this period $J_{i,t}$, and the amount dispatched, $Jout_{i,t}$. Moreover, Eq. (18) enforces that the stock of product in period *t* cannot exceed the maximum available storage capacity JIMAX (5000 ton). Eq. (19) poses that in each time period *t,* fruit juice *i*, $Jout_{i,t}$, is dispatched according to a specific schedule. Since in our case study the product is assumed to be fully devoted to the export market, the dispatch schedule coincides with the arrival of ships to the dispatching port throughout the year. Parameter $SHIP_t$ has large values in those time periods with ship arrivals and is zero otherwise (Appendix A).

Regarding operational features, juice plants are quite flexible. If required each process section can be shut down for several periods and started up again to renew production. Through Eqs. (20)-(27), variables $on1_t$ and $on2_t$ monitor if each process section is started up in a certain time period *t*. The parameter BM stands for a big-M constant. Moreover, transitions between the processing of apple and pear can also take place in each section. These product switches are modeled with variables $sw1_t$ and $sw2_t$ in Eqs. (28)-(35). In order to start-up a processing section as well as to change production to a different product (product switch), the processing units have to be set up, basically cleaned up to avoid product contamination. This set-up time is explicitly considered in the proposed formulation with Eqs. (23), (27), (31), and (35) by preventing production each time period a start-up or a product switch take place.

In order to define the business profit, which is the objective function, OF, of the planning problem, the income and the costs of the production system have to be defined. The sales income, SI, is defined in Eq. (36) as the amount of juice times the corresponding selling price. Since throughout the year the juice price fluctuates, parameter $PJ_{i,t}$ represents a forecast which in a great extent drives the production decisions. Eq. (37) accounts for raw material costs RMC. It should be noted that $I_{i,t}$ is treated as a parameter since it represents an estimation of a fruit production acquired before the harvest season. On the other hand, $C_{i,t}$ is a variable that can take values between zero and the maximum available amount of fruit in the market each day.

The last term of the objective function in Eq. (39) represents the operative costs, OC, calculated by Eq. (38). The operative cost, is made up of a number of items: supplies, labor, energy, fuel, storage, administration and commercialization among others. These items are distributed within the two processing sections (P1 and P2) and the three storage instances (reception site, intermediate product pools and juice cold storage) of the flow-sheet in Fig. 1. Since available data on operating costs usually integrates all these items, only a single term based on the delivered amount of finished product is considered in Eq. (38) (Appendix A). Although this is a reasonable approximation for most of the involved costs, it constitutes an over simplification for the finished product storage cost, which has to be cold stored.

To sum up, the whole MILP model for the production planning of the concentrated juice plant is defined by maximizing the objective function in Eq. (39) subject to Eqs. (1)-(38) plus bounds constraints that may apply.

3 Results and discussion

In this section, the results of the proposed model are analyzed and discussed. The GAMS modeling platform [6] and the solver CPLEX 12.1.0 were used to implement and solve the resulting MILP model. All the experiments were run on a desk computer Intel(R) Core(TM) i3 CPU 530 @2.93 GHz, with 3.27 GB of RAM. A typical run took a few minutes of CPU time.

The complete profiles for model parameters that vary with time or throughout the season are detailed in Appendix A. It should be mentioned that although managers of several juice companies were interviewed to investigate the details of the juice manufacturing business, detailed data from specific firms were not available for publication purposes. However, most of the required inputs are available in different public documents generated by pome fruit business analysts from governmental offices [7-8]. The export ship schedules were downloaded from the statistics section of the San

Antonio Port services provider website [9]. The remaining data were obtained from personal communications with experts in the field.

In this study, two scenario analysis based on years 2009 and 2010 were performed. Due to space reasons, only the analysis of 2009 is reported, followed by a sensitivity study on the process storage capacity and on the slope of the juice production.

3.1 Scenario Analysis

Figure 2 presents model results for scenario inspired on business conditions of year 2009. Only most relevant parameters and variables are reported. In all cases, dashed line represents apple and solid line represents pear. Fig. 2a shows the juice price evolution throughout the year, while Fig. 2b presents the fruit income. The thick line represents the pre-acquired fruit (400 ton/day), while the thin line shows the "on-spot" purchase which is constrained by 200 ton/day. In Fig. 2c the intermediate juice production rates are shown. Finally, Figs. 2d, e, and f show fresh fruit, juice, and intermediate product inventories, respectively. In Table 1, the terms of the objective function are summarized.

From Fig. 2a it is observed that apple juice price was larger than pear juice price throughout practically the whole planning horizon in year 2009. Since apple juice production is therefore clearly favored, additional apple purchases are observed in several periods throughout the apple harvest season. Specifically, a sustained purchase of additional apple takes place from period 52 onwards (Fig. 2b), thin dashed line). Additional pear is only purchased from the beginning of the pear harvest until the beginning of the apple harvest in order to complement the pear juice production of pre-acquired fruit.

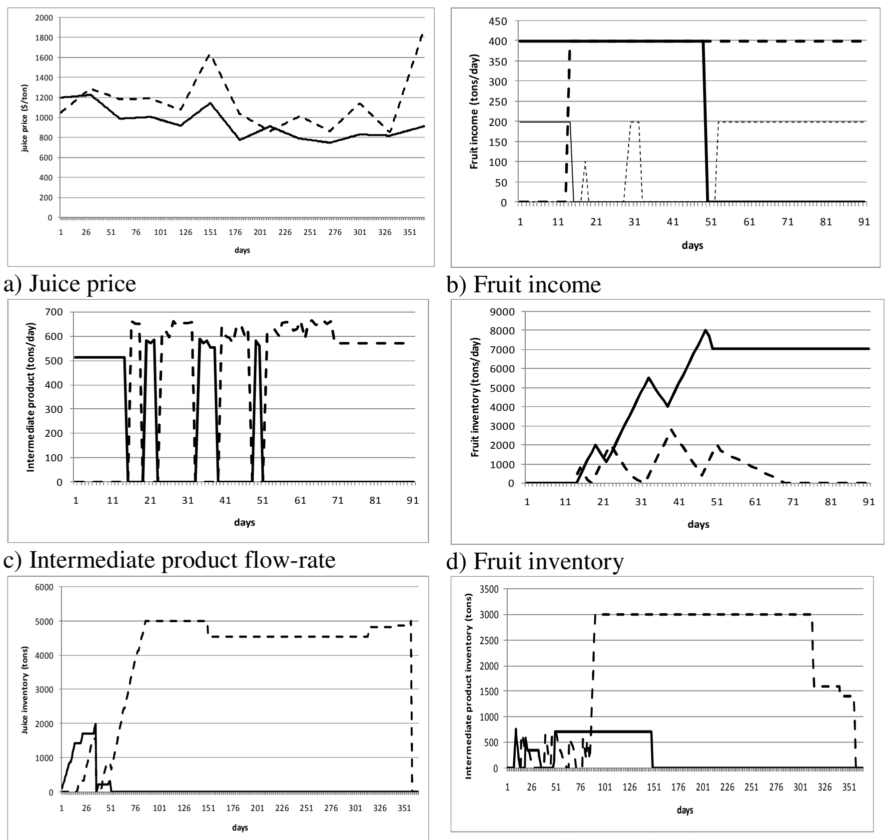
Fig. 2c illustrates that the production of intermediate product switches seven times in process section P1, with apple dominating the last portion of the processing period. This preference translates into a complete depletion of fresh apple by day 70, while a large amount of pear (7000 tons) remains unprocessed at the end of the season (Fig. 2d).

From Fig. 2e it can be seen that pear juice (solid line) is dispatched as soon as possible (days 36 and 51) to exploit the relative high price of the pear during the first half of the season. Interestingly, 700 ton of pear intermediate is stored until day 150 (Fig. 2 f), when it is fully transformed into juice and dispatched to take advantage of the price peak in that date (Fig. 2a). Regarding apple (dashed line), the majority of the juice (Fig. 2 e) and the intermediate product (Fig. 2 f) are saved until the last delivery period (day 358) in order to exploit the exceptionally high price observed in the last month of year 2009.

3.2 Sensitivity analysis

Many inputs of the studied system suffer from significant uncertainty and variability. Moreover, several process parameters have a large impact on the system performance. In order to illustrate this issue, two sensitivity studies were performed: the effect of the storage capacity of the system, followed by an analysis of the slope of the juice yield decay due to storage in the open.

From Figs. 2e) and f), it is observed that both, juice storage capacity and intermediate product storage capacity hit their upper bounds (5000 and 3000 ton respectively) throughout a large portion of the planning horizon. Therefore, these bounds represent bottlenecks for production increase.



a) Juice price
b) Fruit income
c) Intermediate product flow-rate
d) Fruit inventory
e) Juice inventory
f) Intermediate product inventory

Fig. 2. Results for scenario of year 2009 (apple: dashed line, pear: solid line)

Results for increases of 10% and 20% in both capacities (concentrated juice and intermediate product) with respect to the base case situation are summarized in Table 1 for year 2009. It is observed that increments of 4.2% and 8.0% in total profit are obtained, respectively. Interestingly, a reduction in the operating costs is observed in both cases. Since the operating costs are directly associated to the juice production, the increment in total profit is therefore not a consequence of a larger overall juice manufacture but of a selective production of the apple product over the pear juice, in order to take advantage of its favorable price. In other words, larger amounts of apple products can be stored until the last delivery time period when an advantageous selling price compensates a reduced overall production.

The following sensitivity study deals with the impact of the slope of the juice yield decay due to fruit aging during storage. In the base case a slope of 0.02 was adopted, which represents a very mild juice yield reduction with time. In order to investigate the effect of such parameter on the production plan, two alternative values, 0.05 and 0.1, were considered for comparison against the base case of year 2009. These slopes significantly intensify the juice reduction yield. In Table 2, the economic terms are summarized for the three cases. As expected, the total profit reduces with increasing yield decays since for a given processing capacity more fruit has to be processed to obtain the same amount of product.

Larger amounts of additional apple are purchased as the extraction yield decays, in order to compensate for the reduced production. Pear juice is basically produced before the beginning of apple harvest. When apple appears in the scene (day 15), the pear processing is sensibly reduced from three batches in the base case (Fig. 2d), to two for the intermediate slope and to only one batch for the high yield decay.

Table 1. Sensitivity analysis on storage capacity (year 2009)

	Storage capacity		
	Base case	+10%	+20%
Sales income ($)	14534733	14639508	14897914
Raw material cost ($)	3337280	3314131	3361920
Operating cost ($)	6080044	6011794	6006828
Total profit ($)	5117409	5313582	5529167

Although the model procures to exploit as much as possible the availability of pre-acquired pear, large profits are associated to high apple juice deliveries in this scenario due to its dominating price. Therefore, a large pear inventory remains unprocessed at the end of the season, especially in the case of the largest juice yield decay, since it resulted vital to process as much apple as early as possible to avoid apple juice production loss.

Table 2. Sensitivity analysis on juice production decay

	Juice production decay (a_i)		
	0.02	0.05	0.1
Sales income ($)	14534733	14455486	14660352
Raw material cost ($)	3337280	3411200	3720800
Operating cost ($)	6080044	6041717	6076376
Total profit ($)	5117409	5002569	4863175

4 Conclusions and future work

The proposed planning model seeks to optimize the juice business profit throughout a season by deciding which species, apple or pear, to process each day of the planning horizon. The decisions are mostly dictated by the product prices, which are the actual driving forces of the system. In the cases where one of the products presents an advantageous price situation, the model favors its production by purchasing additional raw fruit and prioritizing its processing. However, the availability of pre-acquired raw fruit of both types at low cost generates a solution which includes both products distributed along the delivery schedule.

It should be mentioned, that it was assumed that the plant counts with an appropriate control system, able to implement the proposed schedule. Such level of automation might not be present in current juice plants and therefore the obtained solution could not be easily implemented in practice. However, the obtained results highlight the potential benefits of working with an improved processing structure and more sophisticated control systems.

Additionally, many model parameters present a significant uncertainty, specifically those that somehow depend on climatic conditions, such as the juice yield decay and the raw fruit availability. Moreover, an accurate one year juice price forecast is hardly available, since it is dictated by worldwide supply-demand tradeoffs. It is well known that uncertainty should be explicitly handled in real applications. A practical solution could be to run the model within a model predictive control framework [10] in order to identify the short term optimal solution with the available forecast, and recalculate a new forehead solution as the information of the system is updated.

Finally, the proposed model might be also used in a design mode by performing scenario analysis based on prices estimations, in order to determine the convenient fruit volumes to purchase before the season and to calculate the optimum storage capacity to improve the business operations.

Appendix A

Fruit income. The harvest calendar for nine typical apple and pear varieties produced in the “Alto Valle” region is given in [11] (see Table 5 in Supplementary data). The fruit income profile to the plant is made up by the production committed before the season with specific producers, plus the additional (on-spot) acquired fruit. For the purposes of the present contribution it is assumed that 400 ton/day of the harvested varieties enters the system as pre-acquired production each day and that a maximum of 200 ton/day of the harvested fruit is available for on-spot purchase if required. Additional fruit might be available on the market for processing outside the harvest season.

Juice yield loss due to fruit aging. Stored fruit in the open experiments juice yield reduction with time due to the ripening process. Juice yield loss with time is difficult to predict since it depends on the specific fruit variety and on the storage conditions. In this work, a simple approach is proposed which consists in a linear relationship with a saturation scheme to avoid negative yields (Eq. (A1)). The yield loss slope, a_i, can be therefore modified to study different scenarios. If more accurate relationships become available, they can be easily included within the formulation. The following figures are adopted for base case analysis: $YIELD_{pear,1}$= 0.85, a_{pear}=0.02, $YIELD_{apple,1}$= 0.95, a_{apple}= 0.02.

$$YIELD1_{i,e} = \max \{ YIELD_{i,1} - a_i.(ord(e) - 1), 0.0 \} \qquad (A1)$$

Costs and prices. In [8] fresh fruit and operating costs for years 2009 and 2010 are provided. Additionally, the average free-on-board price for both juice varieties in each month of these years is also reported. A linear combination between consecutive values is adopted to provide a price value for each day of the planning horizon.

*Juice delivery.*Table A1 provides the ships schedules of the San Antonio Port during years 2009 and 2010. It is assumed that each period that a ship is in the port, an unlimited amount of juice can be embarked with overseas destiny.

Table A1. Ships schedule (time periods)

2009	36-51-68-84-99-111-121-132-150-207-247-343-358
2010	43-50-55-67-114-130-180-221-278-351

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