PRODUCT MIX OPTIMIZATION OF FRUIT NECTAR WITH INTEGRATION OF ANALYTIC HIERARCHY PROCESS AND MATHEMATICAL PROGRAMMING

Adem ERİK[1*], Burcu DÜNDAR[2], Durmuş Can ACER[3]

[1]Çukurova University, Industrial Engineering Department, Adana, Turkey
ORCID No: https://orcid.org/0000-0001-6840-0586
[2]Çukurova University, Food Engineering Department, Adana, Turkey
ORCID No: https://orcid.org/0000-0002-9919-5711
[3]Çukurova University, Mechanical Engineering Department, Adana, Turkey
ORCID No: https://orcid.org/0000-0003-1068-7873

Anahtar Keywords

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Abstract

Today, the competitiveness of companies is directly dependent on the quality and price of their products. This is because consumers have more options to buy a product than in previous years. In this study, two different mathematical models are developed to determine the best product mix according to different constraints for a fruit nectar producer. 4 main and 9 sub-quality criteria, whose importance levels were determined by the analytical hierarchy process (AHP) method, were used as inputs in two mathematical models that found the optimum product mix. These models, created for optimum product mix, consider not only the integrated quality criteria but also different constraints such as capacity, labor, and raw material. Models aiming at breakeven and maximum profit have been run for different scenarios such as consumer demands, machine maintenance, and the increase in bottlenecks. The results have shown that the quality criteria change the production efficiency and sales quantities, and how much the existing production system can adapt if consumer demands change.

ANALİTİK HİYERARŞİ PROSESİ VE MATEMATİKSEL PROGRAMLAMA ENTEGRASYONU İLE MEYVE NEKTARI ÜRÜN KARMASI OPTİMİZASYONU

Kelimeler

Analitik Hiyerarşi Prosesi, Optimizasyon, Meyve Nektarı Üretimi, Başabaş Noktası, Matematiksel Modelleme

Öz

Günümüzde firmaların rekabet gücü doğrudan ürünlerinin kalitesine ve fiyatına bağlıdır. Bunun nedeni, tüketicilerin bir ürünü satın almak için önceki yıllara göre daha fazla seçeneğe sahip olmasıdır. Bu çalışmada, bir meyve nektarı üreticisi için farklı kısıtlara göre en iyi ürün karmasını belirlemek için iki farklı matematiksel model geliştirilmiştir. Analitik hiyerarşi süreci (AHP) yöntemi ile önem seviyeleri belirlenen 4 ana ve 9 alt kalite kriteri optimum ürün karmasını bulan iki matematiksel modelde girdi olarak kullanılmıştır. Optimum ürün karması için oluşturulan bu modeller, sadece entegre kalite kriterlerini değil aynı zamanda kapasite, işçilik, hammadde gibi farklı kısıtları da dikkate almaktadır. Tüketici talepleri, makine bakımı, darboğazların artması gibi farklı senaryolar için başabaş ve maksimum karı hedefleyen modeller çalıştırılmıştır. Sonuçlar, kalite kriterlerinin üretim verimliliğini ve satış miktarlarını değiştirdiğini ve tüketici talepleri değiştiğinde mevcut üretim sisteminin ne kadar uyum sağlayabileceğini göstermiştir.

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*Sorumlu yazar; e-posta: ademerik@tarsus.edu.tr

1. Introduction

In recent years, while producers aim to decrease cost of juice/nectar in industry, consumers' demand for not only cheap, but also healthier food has been increasing. However, there is no optimization study considering the quality (with the effect of raw materials) and cost (with the effect of heat exchangers) together in literature. The differences in the quality properties (bioactive compounds, color, sensorial attributes etc.) of raw material have a great impact on the final juice/nectar product. Also, this quality parameters of juice/nectar are affected in the thermal treatment (pasteurization) part of processing. Therefore, as a fruit juice/nectar producer, besides minimizing the cost, it will be very beneficial to optimize the quality of product by mixing and evaluating raw materials with different quality characteristics (orange, lemon, mandarin and grapefruit) and controling the effect of the heat exchanger on yield and product.

Citrus is one of the most important fruit crops with a high level of bioactive content and is consumed mostly as fresh or juice. Bioactive compounds have a positive effect on human health and preventive effect on different kinds of cancer, cardiovascular and neurological diseases, and aging-related disorders because of their antioxidant activities (Sun, Chu, Wu and Liu, 2002). Therefore, protecting bioactive compounds (vitamin C, carotenoid and phenolic compounds) of juice to obtain a product with higher antioxidant activity can be worthwhile. Besides pH, oxygen and light, the degradation of bioactive compounds is depended on mainly thermal processing conditions (Burdurlu, Koca and Karadeniz, 2006; Laing, Schlueter and Labuza, 1978; Lee and Coates, 1999).

Another quality criterion that is effective on consumer preference of nectar is color. The color of food can be determined with three main parameters which are brightness (L* value), redness (a* value), and yellowness (b* value). Also, other sensorial attributes (taste, smell, and overall acceptance) are directly effective on the consumption of nectar. On the other hand, a precursor (hydroxymethylfurfural, HMF) of undesirable brown pigments which can occur as a result of thermal treatments and improper storage conditions in fruit products (Clegg, 1964). Besides the destructive effect of thermal processing on the color of the juice, HMF has genotoxic, mutagenic, carcinogenic, DNA-damaging, organotoxic, and enzyme inhibitory effects (Shapla, Solayman, Alam, Khalil and Gan, 2018). The formation of this substance, which increases during heat treatment and storage, should be limited in fruit juices (Yıldız et al., 2010). These quality properties of fruit juices including orange, carrot, pomegranate, and apple juices might be affected negatively after thermal treatment (Vegara, Marti, Mena, Saura and Valero, 2013; Mehmood et al., 2008; Rivas, Rodrigo, Martinez, Barbosa-Cánovas and Rodrigo, 2006). Therefore, quality features of fruit nectar can be examined under four groups as color, bioactive substance contents, sensory properties, and HMF content as heat treatment contaminant.

Researchers have used various optimization tools for different engineering problems such as electric vehicle charging infrastructure at workplaces (Erdogan, Pamucar, Kucuksari, and Deveci, 2021), sandwich structures with better stiffness-to-weight ratio (Uzay, Acer, and Geren, 2021), mall location selection for a city (Yavuz and Deveci, 2014), and to find best tax scheme for financing public transit investments (Simic, Gokasar, Deveci, and Isik, 2021). For the food industry, there are many studies aiming quality optimization of different kinds of treatments that were applied to the juice (Demirdöven and Baysal, 2014; Silva and Silva, 1997; Singh, Khemariya and Rai, 2014; Dündar, Ağçam and Akyıldız, 2019; Koshani, Ziaee, Niakousari and Golmakani, 2015). An organization can compete with other organizations only by using resources efficiently and making maximum profit (Lukic, Kljenak and Anđelić, 2020), but also improving the quality of product. Proper and efficient use of resources is to produce the products demanded and profitable in the right amounts (Ross, 2013). Product mix optimization can be considered as the problem of optimizing costs to achieve maximum profit under certain resource constraints (Rajesh, 2020). Chung, Lee and Pearn (2005), proposed the analytic network process (ANP) for the selection of the product mix in a semiconductor manufacturer. They presented several factors for different product mixes and a hierarchical network model for the interaction of these factors. By adding expert opinions to the network model, priorities were created for each product mix, and the most efficient product combine, which considers product, equipment efficiency, and finance aspects, was selected. Vasant and Barsoum (2006), proposed to make a product mix decision by applying fuzzy linear programming (FLP) to the data received from a chocolate manufacturing company. It was seen that the fuzzy product mix problem defined by the S-curve membership function methodology depends on the uncertainty factor. Tsai, Wang and Tzeng (2010), suggest a conditional value at risk minimization (CVaRM) approach to optimize an insurer's product mix. The optimized product mix was calculated for insurance companies to protect against the systematic mortality risk under the parameter uncertainty by integrated the natural hedging strategy and the two-factor stochastic death model.

In optimizing a product mix, demands, production capabilities, and capacities are optimally matched. Romauch and Klemmt (2015), developed linear programming that takes into account plant capacity, demands, and profits to find product mix in a semiconductor manufacturing facility. Tanhaie and Nahavandi (2017), presented the goal programming approach for the product mix problem that affects performance measurements in the multi-product production system. The authors stated that the theory of constraints was insufficient in bottlenecks, and they considered the decision-maker idea to determine the weight of objective functions with efficiency and bottleneck exploitation. Yu, Kuo, Chiu, Wen and Zahang (2021), determined the effects of product mix on the factors (process time, cycle time, usable vehicle, etc.) using artificial neural networks. They were found a product mix optimizing the required production cycle time using a genetic algorithm. Molina (2018) has created the parameters of linear programming with data from online clothing store owners. The linear model aimed to determine the most economical product mix for purchasing from suppliers and benefited. They used QM for Windows software for finding the most suitable solution.

To the best of our knowledge there is no study with the aim of juice production cost optimization and ensuring the acceptable level of quality of juice at the same time. This study, it is aimed to determine the product mix that brings POLIMAG company, which produces fruit nectar from different citrus fruits to breakeven point in the fastest way, and the product mix that provides maximum profitability. For the first time with this purpose, AHP method was used in this study. When determining the product mix, a mathematical model was created by considering the market demands and the quality expectation of the consumer. The AHP method, which takes expert opinions into account, was used to determine the quality level in the created model. The effects of quality and machine constraints on the product mix have been revealed. Although many studies using different multi-criteria decision-making methods on quality and different mathematical models for product mix optimization in product manufacturing, as far as we know, no study examines them in an integrated way. At the same time, the absence of a similar study in the field of fruit nectar manufacturing makes the study important.

2. Methodology

The optimum solution was found for the product mix problem using an integrated way consisting of AHP and mathematical modeling methods. The AHP method is broadly spread, and it is one of the known most reliable methods for weighting. It has an easily usable, reasonable system. It disentangles a troublesome issue by separating it into little steps. The AHP method does not require authentic information sets (Kaliyamurthi, 2017). Because of all these reasons, the AHP method was used for weighting in this paper. Among these methods, AHP revealed how heat exchanger machines, which directly affect the quality of fruit nectars, affect the product in different criteria. The quality criteria determined by the experts were weighted with the AHP method and these weights obtained here are included as input to the created mathematical model. In advanced mathematical programming, there are two different objective functions provide the product mixes that reach the break-even point fastest and obtain the maximum profit. This situation affects the resource usage of the model and the product mix result. The methodology used is shown in Figure 1. Accordingly, optimum product mixes have been obtained in the model where different scenarios are also considered. In this study, research and publication ethics have complied.

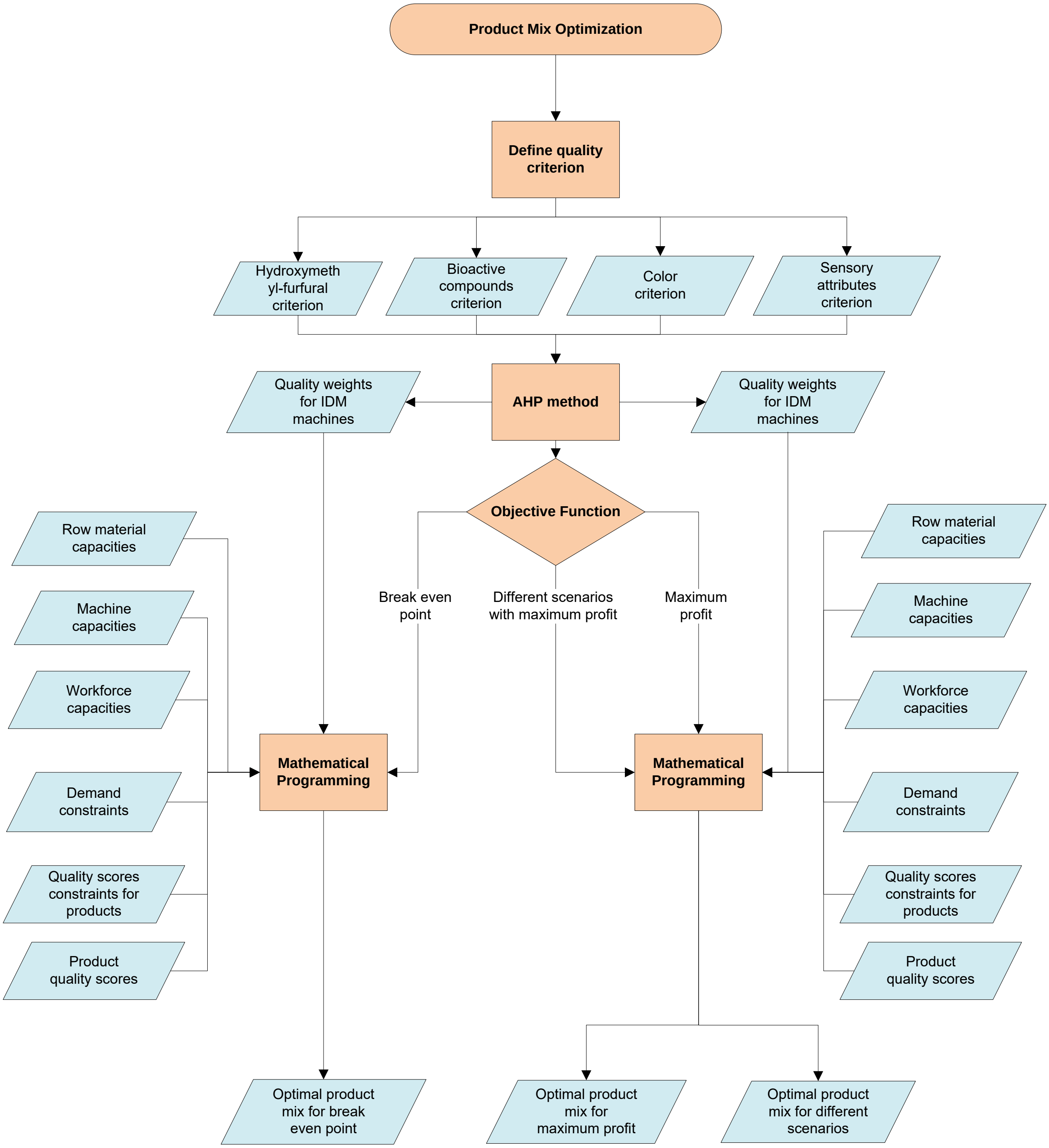

Figure 1. Solution Methodology of Products Mix Optimization (IDM: Heat exchanger)

2.1 Analytic Hierarchy Process Method

The analytical hierarchy process (AHP) is a method that systematically configures decision problems using hierarchies (Saaty, 1980). Making decisions to establish priorities can be summarized with the following steps (Saaty, 2008).

1. The problem and the type of information to be used are determined.
2. In the decision hierarchy, goals are structured from intermediate levels (to which the next items depend) to the lowest level, with the goal at the top.
3. By creating a series of binary comparison matrices, each element at the upper level is compared to the lower-level element.
4. A scale of 1/9 to 9 is used to prioritize the criteria. In order to determine the priorities of

the criteria, comparisons are made according to this scale. A global priority is achieved when the weight of each criterion is added to these comparisons.

The binary comparison method is used to compare two criteria or alternatives at any time. With this method, the relationship between the criteria can be clearly examined (Kokangul and Susuz, 2009).

Saaty (1980) used 1 for equal importance; 3 for medium importance; 5 for strong importance; 7 for very strong importance; 9 for extreme importance, and 2, 4, 6, 8 for evaluations in between when comparing criteria. Binary comparison matrices are created by binary comparison of alternatives or criteria. Binary comparison matrix consistency is done by calculating the consistency ratio for each matrix. The consistency ratio is calculated as the consistency index / random index according to Saaty (1980).

Consistency index = $(\lambda_{max} - n)/(n-1)$

Here λ_{max}, is the largest value of the considered matrix. The random index is given according to the number of criteria and the consistency rate is suggested to be 10% or less. At larger values, the matrix is considered inconsistent and binary comparison weights should be revised. By combining the weight of the criteria and alternatives, the total weight of each alternative is calculated.

2.2 Mathematical Model

In the mathematical model, raw material, labor, and energy expenses are considered as variable costs, while rent, machinery investment, and other general expenses are considered as fixed costs.

Indexes

i: *Number of products* $i = 1,2, \dots, N$

j: *Number of row materials* $j = 1,2, \dots, M$

l: *Number of heath exchanger machines* $l = 1,2, \dots, L$

k: *Number of press machine* $k = 1,2, \dots, K$

Decision variables:

a_{il}: *the amount of the ith product processed in the lth heath exchanger (ton)*

x_i: *the amount of ith product produced (ton)*

Parameters

s_i: *sales price of the ith product (\$/ton)*

p_{ij}: *percentage rate of the jth raw material used in the ith product (%)*

f_j: *unit price of the jth raw material (\$/ton)*

l_i: *unit labour time of the ith product (man − hour/ton)*

e_i: *unit energy cost of the ith product (\$/ton)*

M_k: *total capacity of the kth press machine (hour)*

R_j: *total amount of the jth raw material (ton)*

H_l: *total capacity of the lth heat exchanger (hour)*

q_{il}: *quality value of the ith product processed in the lth heat exchanger*

Q_i: *desired quality value of the ith product*

h_{il}: *unit processing time of the ith product processed in the lth heat exchanger (hour/ton)*

W: *total workforce capacity (man − hour)*

D: *total fixed cost (\$)*

U_i: *maximum demand for ith product (ton)*

A_i: *minimum demand for ith product (ton)*

i: unit labor cost (\$/man − hour)

Objective function

$$MinZ = y \quad (1)$$

Constraints

$$\sum_{i=1}^{N} s_i * x_i - \sum_{i=1}^{N}\sum_{j=1}^{M} p_{ij} * f_j * x_i - \sum_{i=1}^{N} l_i * i * x_i - \sum_{i=1}^{N} e_i * x_i - D = y \quad (2)$$

$$\sum_{i=1}^{N} p_{ij} * x_i \le R_j, \forall j \quad (3)$$

$$\sum_{i=1}^{N} l_i * x_i \le W \quad (4)$$

$$\sum_{i=1}^{N} h_{il} * a_{il} \le H_l, \forall l \quad (5)$$

$$\sum_{l=1}^{L} \frac{a_{il} * q_{il}}{x_i} \geq Q_i \text{ ,} \forall i \quad (6)$$

$$\sum_{l=1}^{L} a_{il} = x_i \text{ ,} \forall i \quad (7)$$

$$X_i \leq U_i, \forall i \quad (8)$$

$$X_i \geq A_i, \forall i \quad (9)$$

$$\sum_{i=1}^{N} t_{ik} * x_i \leq M_k \text{ ,} \forall k \quad (10)$$

$$y \geq 0, x_i \geq 0, a_{il} \geq 0 \quad (11)$$

In the model created, the objective function (1) balances the sum of the variable and fixed costs with the sales amount obtained according to the production. Calculations of the variable y, which is balanced in the objective function, are made in equation (2). Equation (3) shows that the number of raw materials used in production cannot exceed the raw material capacity. Equation (4) states that the total workforce used for production cannot exceed the total workforce capacity of the company. Equation (5) states that the duration of the products processed in heat exchange machines cannot exceed the capacity of these machines. Equation (6) ensures that the quality scores of the products produced in each heat exchanger machine remain above a certain quality value. Equation (7) shows that the total amount of product processed in heat exchangers must be equal to the total product produced. Equation (8) states that the amount of product produced must be smaller than the maximum demand, while equation (9) states that it must be greater than the minimum demand. Equation (10) states that the press machine time used for production cannot exceed the total capacity of this machine. Finally, equation (11) states that final product quantities and intermediate product quantities processed in heat exchangers must be positive. Then, the objective function in the first mathematical model is arranged as in equation (12) to obtain maximum profit in the second mathematical model. Besides that, the variable y is not needed in the second mathematical model. Because the second model's objective obtains the product mix that provides the maximum profit.

$$MaxZ = \sum_{i=1}^{N} s_i * x_i - \sum_{i=1}^{N}\sum_{j=1}^{M} p_{ij} * f_j * x_i - \sum_{i=1}^{N} l_i * i * x_i - \sum_{i=1}^{N} e_i * x_i - D \quad (12)$$

In addition, equation (8), which is the maximum demand constraint, has been removed from the model to find the product mix that will obtain the maximum profit. In this way, the production tendency of the company was seen.

3. Case Study

POLIMAG Company was established in Adana to produce fruit nectar from citrus. The company produces fruit nectar from oranges, mandarins, lemons, and grapefruits grown in the fields in Adana and sells them in 1-liter cans, according to the demands of the customers. Fresh citrus can be found in Adana between October and March. The company should create a product mix that reaches the breakeven point as quickly as possible. In the face-to-face interviews with the company, the information required for case analysis was obtained by accordance with publication ethics. Written permission has been obtained from the company to use this information

According to the market research, the sales prices of four products in the production plan were determined as $845 /ton for orange nectar, $1560 /ton for lemon nectar, $702 /ton for mandarin nectar, and $1404 /ton for grapefruit nectar. Moreover, in this research, it was determined that the maximum demand was 100 tons for orange nectar, 80 tons for lemon nectar, 120 tons for mandarin nectar, and 80 tons for grapefruit nectar. It is known that the company has a monthly fixed order of 20 tons, 30 tons for lemon nectar, 25 tons for mandarin nectar, and 35 tons for grapefruit nectar. Unlike fruit juice, in the production of fruit nectar, sugar, water, and organic acid are added to the mixture in proportions that will not spoil the taste balance. Fruit nectar is defined as "unfermented, but fermentable products obtained by adding sugar and/or honey and water to the fruit juice, fruit juice concentrate, fruit puree or their mixture" (Galaverna and Dall'Asta, 2014). A total of seven different raw materials will be used for the nectars produced in the factory. The maximum amounts that can be supplied monthly from these raw materials are 800, 500, 700, 100, and 100 tons for orange, lemon, mandarin, grapefruit, and sugar, respectively. There is no supply constraint for water and acid raw materials. Percentage use of raw materials and unit costs of them are given in Table 1.

Table 1
Raw Material Using Ratios (%) and Their Unit Costs ($/Ton)

Products	Raw Materials Usage (%)						
	Orange	Lemon	Mandarin	Grapefruit	Water	Sugar	O. Acid
Orange nectar	80	0	0	0	19.5	0	0.5
Lemon nectar	0	55	0	0	30	15	0
Mandarin nectar	0	0	75	0	24	0	1
Grapefruit nectar	0	0	0	70	15	14.7	0.3
Unit costs($/ton)	4000	7900	5000	3000	12	6450	22000

Fruit nectar is produced at the factory for an average of 22 working days per month. There are three working shifts in the factory and 15 personnel works in each shift. There is a monthly expense of $24000 for 45 employees working in total. According to the analysis made at the factory, the unit labor time for orange, lemon, mandarin, and grapefruit nectars was 1.88, 3, 2.50, and 1.67 man*hour/ton and the cost of one man*hour labor was 2.95 $. In addition, the unit variable energy expense for orange, lemon, mandarin, and grapefruit nectars was calculated as $0.31, $0.49, $0.41, and $0.27 per ton, respectively. The sum of fixed costs that occurred during production at the factory was calculated as $195000.

The company has two press machines (PM1, PM2) and three heat exchangers (IDM1, IDM2, IDM3) with different capacities. The fruit is processed first in press machines and then in heat exchangers. Along with the fruit nectar production line, presses in which fruit nectar is applied to the raw material is extracted and pasteurization, where heat treatment is applied to the fruit nectar, are among the processes that cause the most important effect on quality (Tüfekci and Fenercioğlu, 2010). In addition, while all other machines used along the production line have the same features, there are multiple options for presses and heat exchangers. The total capacity and product processing times of these machines are given in Table 2.

Table 2
Processing Time (Hours) and Total Capacity (Hours) of Press (PM) and Heat Exchanger (IDM) Machines

	Machines				
	PM1	PM2	IDM1	IDM2	IDM3
Orange nectar	0.28	0.54	0.35	0.4	0.3
Lemon nectar	0.30	0.62	0.45	0.5	0.4
Mandarin nectar	0.32	0.58	0.55	0.5	0.45
Grapefruit nectar	0.25	0.45	0.45	0.4	0.5
Total capacity	369.6	475.2	396	475.2	448.8

An analytic hierarchy process approach was used to determine the importance of changes in color (R), bioactive substance contents (B), sensory evaluation (D), and hydroxymethylfurfural content (H) that heat exchangers effect on product quality. Sub-criteria were also set for the determined criteria and the analysis was detailed. The L*, a*, b* values (color parameters) indicate lightness, redness, and yellowness of the food, and have a relation with the overall acceptance, one of the sensory attributes of juice. Also, carotenoid compounds are responsible from the characteristic color of citrus, and affect the a* value, while HMF content can be highly correlated with the L* value. On the other hand, taste and aroma are evaluated separately in many studies by panelists, while overall acceptance score covers all of the sensory attributes including them (Costa et al., 2020; Dias et al., 2020). The determination and comparison of criteria that facilitate decision-making on a subject are made by experts in this field. In this article, criteria were determined by experienced food engineers in fruit juice and nectar production. The comparison of the determined criteria was also carried out by these experts. Table 3 shows the pairwise comparison of the 4 main criteria. Similarly, pairwise comparisons were repeated for sub-criteria and IDM machines.

Table 3
The pairwise comparison of main criteria

Main Criteria	Color	Bioactive Compounds	Sensory Attributes	Hydroxymethylfurfural
Color	1.00	0.20	0.33	0.14
Bioactive Compounds	5.00	1.00	3.00	0.50
Sensory Attributes	3.03	0.33	1.00	0.20
Hydroxymethylfurfural	7.00	2.00	5.00	1.00

After the pairwise comparisons are made, the degree of importance of the criteria relative to each other is revealed and the weights of each criterion are obtained. The weights of main and sub-criteria used in the case study are shown in Figure 2.

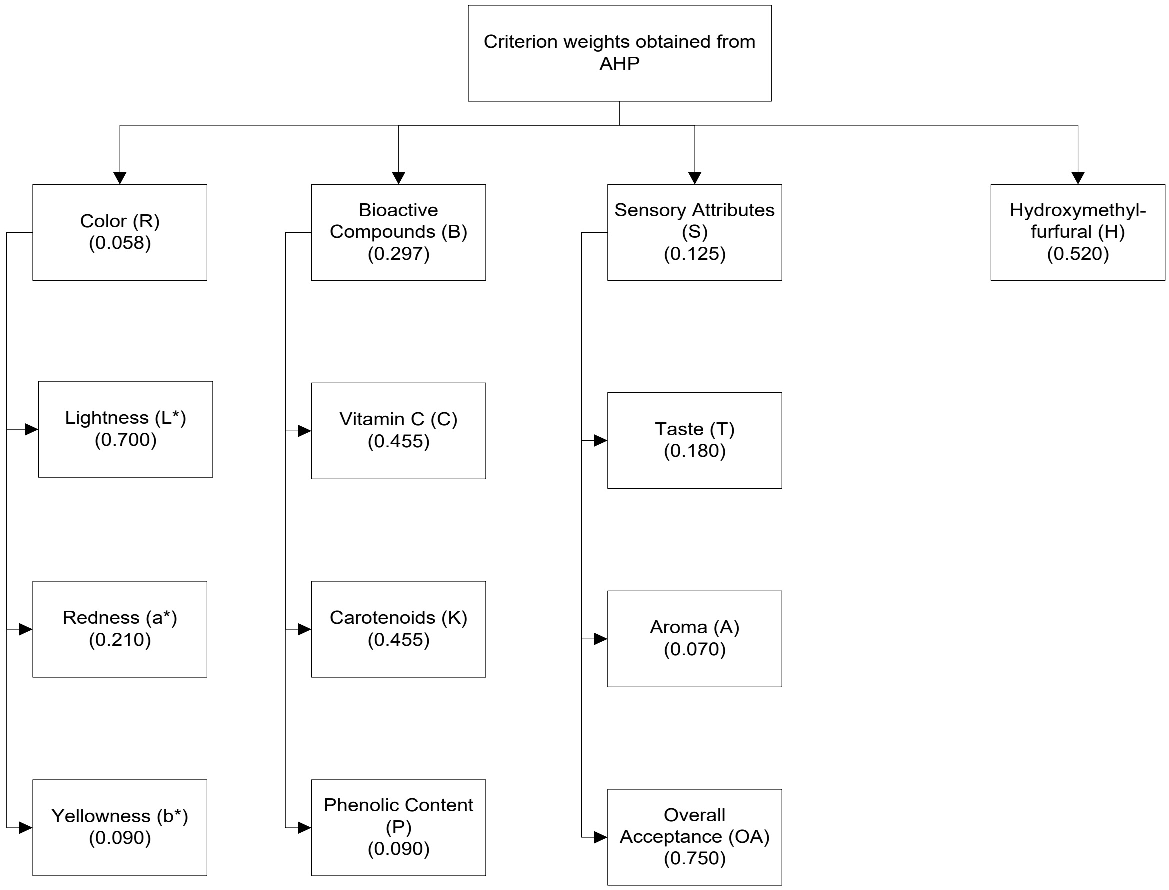

Figure 2. Criterion Weights Obtained from AHP

The quality control department has determined minimum quality values for products based on feedback from consumers. Thus, the agreed quality values were 3.8 for orange nectar, 3.5 for lemon nectar, 3.75 for mandarin nectar, and 3 for grapefruit nectar. These values are scored on a 5-point scale considering the criteria determined by the experts. In Figure 3, it is given in which quality it is produced according to the IDM machine it is produced for each product. The effect of criteria on product quality is also stated in the same figure. These values have been converted to the range of 0-5 to be compared with the demands of the customers in the mathematical model. The quality of the products processed in the heat exchanger is found by multiplying the criteria weights (Figure 2), with the weights (Figure 3) obtained because of the comparison of the heat exchanger machines.

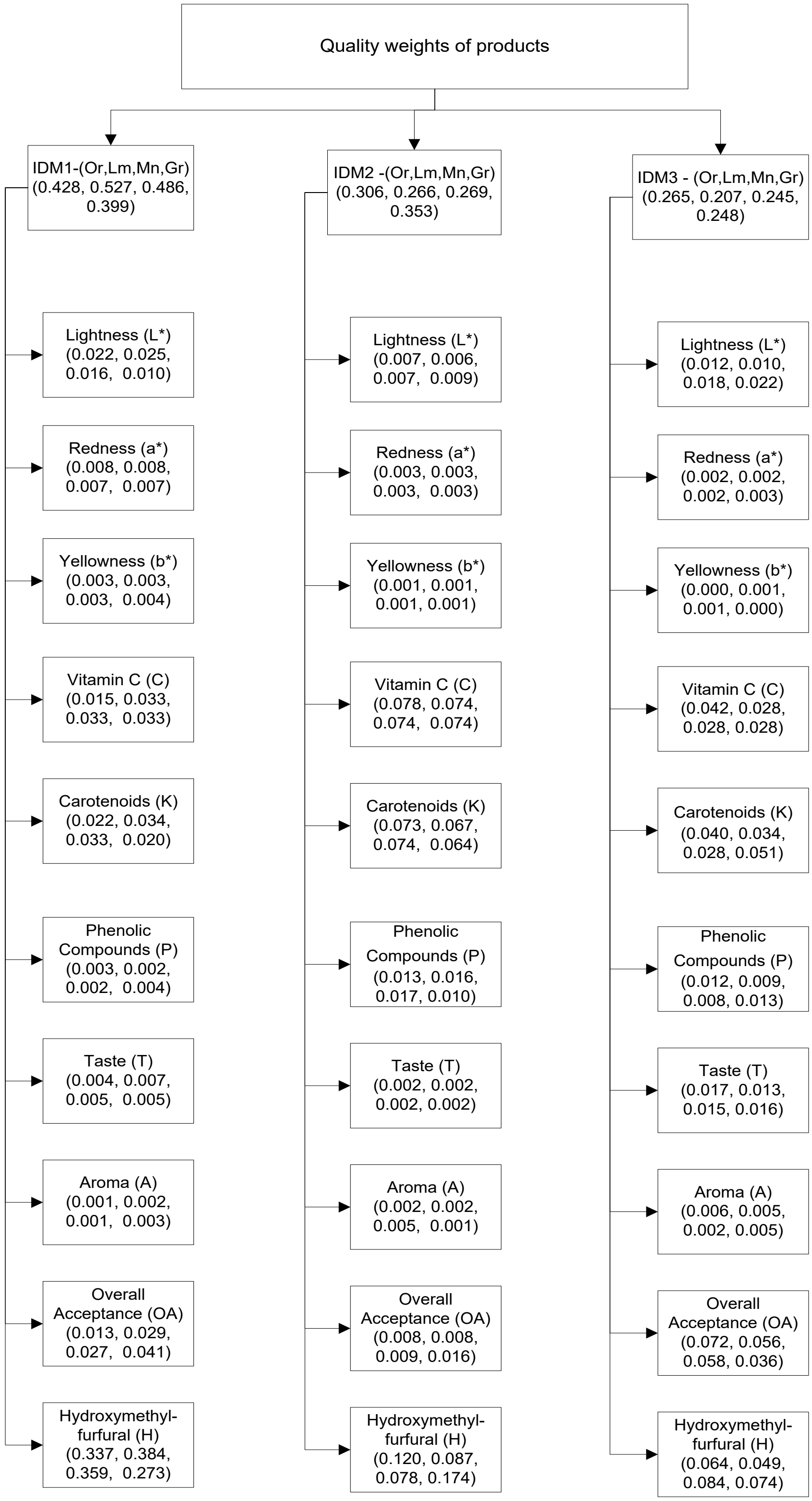

Figure 3. Quality weights of products produced on different IDM (heat exchanger) machines (Or: Orange, Lm: Lemon, Mn: Mandarin, Gr: Grapefruit)

There are consistency ratios that prevent the pairwise comparisons made in the AHP method from being wrong. Accordingly, consistency ratios should be calculated for each pairwise comparison matrix. Thus, the accuracy of the evaluation is checked. The consistency ratios calculated for the pairwise comparisons made in the study are shown in Table 4.

Table 4
Consistency ratios for pairwise comparisons (IDM: Heat exchanger)

Consistency index for weighting criteria	
Main criteria	8 %
Color	6 %
Sensory Attributes	6 %
Bioactive Compounds	0 %
Consistency index for benchmarking IDMs	
Lightness	2 %
Redness	1 %
Yellowness	10 %
Vitamin C	1 %
Carotenoids	2 %
Phenolic Content	1 %
Taste	10 %
Aroma	5 %
Overall Acceptance	10 %
Hydroxymethylfurfural	1 %

As a result of the analysis made for the fruit nectars produced by the POLIMAG Company, the product mix and quantities that need to be produced to reach the break-even point are given in Table 5. According to the results of the mathematical model that finds the breakeven point, when production is made up to maximum demand from products other than mandarin nectar, the break-even point was reached when 55.556 tons of mandarin nectar were produced. Mandarin nectar production was found to be the last choice in the product mix of the model.

Table 5
Nectar Production Amounts That Provide a Breakeven Point in The Shortest Time

Products	Quantity (tons)
Orange nectar	90.237
Lemon nectar	80.000
Mandarin nectar	55.556
Grapefruit nectar	80.000

The compliance of the products with the quality values obtained because of market research depends on the heat exchangers (IDM). The minimum quality value required for a product is achieved by mixing intermediate products processed in different heat exchanger machines in certain proportions. According to the results of the mathematical model, the number of intermediate products that must be processed in heat exchangers for the end products to be of appropriate quality are given in Table 6. IDM3 machine reduces the product quality significantly but processes high amounts of product. On the other hand, the IDM2 machine does not process products despite its high processing quality. IDM2 machine processes less amount of product despite its high processing quality. This is due to the tendency of the model to produce products with high profitability and high capacity after reaching sufficient quality value.

Table 6
Nectar Amounts Processed in Heat Exchangers (IDMs) (The Breakeven Point)

	Machines			
	IDM1(tons)	IDM2(tons)	IDM3(tons)	Total(tons)
Orange nectar	75.100	-	15.137	90.237
Lemon nectar	40.526	-	39.474	80.000
Mandarin nectar	34.692	-	20.864	55.556
Grapefruit nectar	36.111	-	43.889	80.000

After the changes made in the model, the product mix that will provide the maximum profit of the company is directed to the production of lemon and grapefruit nectar instead of meeting the agreed demands. Therefore, if 228.904 tons of lemon nectar and 142.857 tons of grapefruit nectar are produced, the profit of the company reaches $156.325, which is the maximum profit. When looking at the heat exchanger machines, it is seen that the second machine is still not used while providing the quality constraint, and the amount of product processed in other machines was realized as shown in table 7.

Table 7
Nectar Amounts Processed in Heat Exchangers (Maximum Profit)

	Machines			
	IDM1(tons)	IDM2(tons)	IDM3(tons)	Total(tons)
Orange nectar	16.645	-	3.355	20.000
Lemon nectar	115.958	-	112.946	228.904
Mandarin nectar	15.611	-	9.389	25.000
Grapefruit nectar	64.484	-	78.373	142.857

4. Scenario analysis

In this section, the mathematical model developed using AHP and break-even point analysis has been examined to determine the optimum product mix. In order to see how the mathematical model works in different scenarios, some cases that may occur have been revealed. These cases were adapted to the model in different scenarios and their results were analyzed. Scenario 1 is that Increasing/decreasing product quality due to machines. The cases examined in Scenario 1 are shown in Table 8.

Table 8
Cases Examined in Scenario 1

Scenarios	Examined cases
S1.0	No quality changes due to machines
S1.1	5% loss of quality in the first machine
S1.2	10% loss of quality in the first machine
S1.3	15% quality improvement in the second machine
S1.4	30% quality improvement in the second machine
S1.5	15% quality improvement in the third machine
S1.6	30% quality improvement in the third machine
S1.7	60% quality improvement in the third machine
S1.8	90% quality improvement in the third machine

An increase in the quality of the products due to the machine maintenance performed in the company or the decrease in the product quality due to various reasons is discussed in scenario 1. For the 8 cases examined, the amount of profit does not change with the increase in quality, and the deterioration in quality causes the customer demands not to be met at the desired level. In Figure 4, machines' utilization rates and their averages obtained for each scenario are indicated. As a result of increasing the quality with machine updates, the machines preferred by the mathematical model change. However, the average machine utilization rate gives close results as the amount of product produced does not change. When the S1.2 case is examined, it is seen that it cannot meet the customer demands because it cannot meet the quality criteria. In other feasible cases, the average utilization rate of the three machines is around 14-15%. This indicates that heat exchanger machines can be used to produce more products if the company increases its resources, which are the bottlenecks.

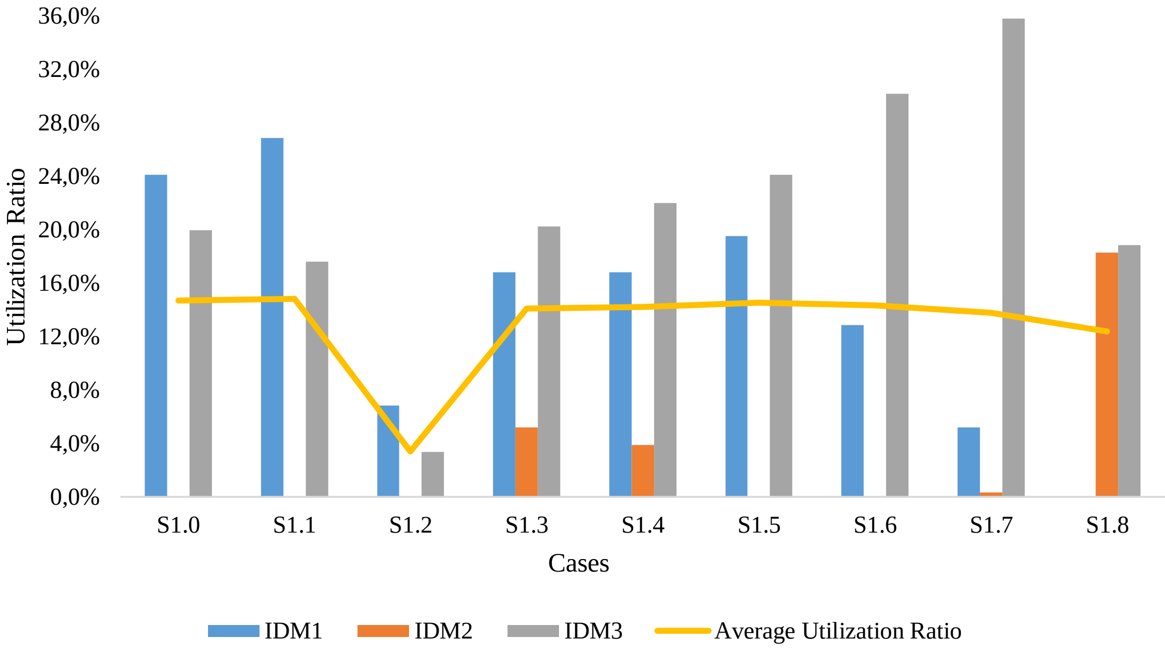

Figure 4. Heat Exchanger Machines (IDMs) Utilization Ratios

In the second scenario, bottleneck resources are excluded, unlike in the first scenario. Thus, cases in which heat exchanger machines affect product quality have been examined again. The elimination of bottlenecks increased the number of products produced and consequently increased the earnings. Among the cases examined, S2.2 could not meet the quality criteria and customer demands, so the desired amount of product could not be produced. In the other 7 cases, the product mix has changed with the quality improvements in the machines and the optimum product mix has been made up of different products in different quantities. The product mixes obtained for the cases examined are shown in Figure 5. Accordingly, in all cases except for S2.2, customer demand has been met and the optimum product mix has been created. The average utilization rate of heat exchanger machines has exceeded 95%, and this has become a new bottleneck.

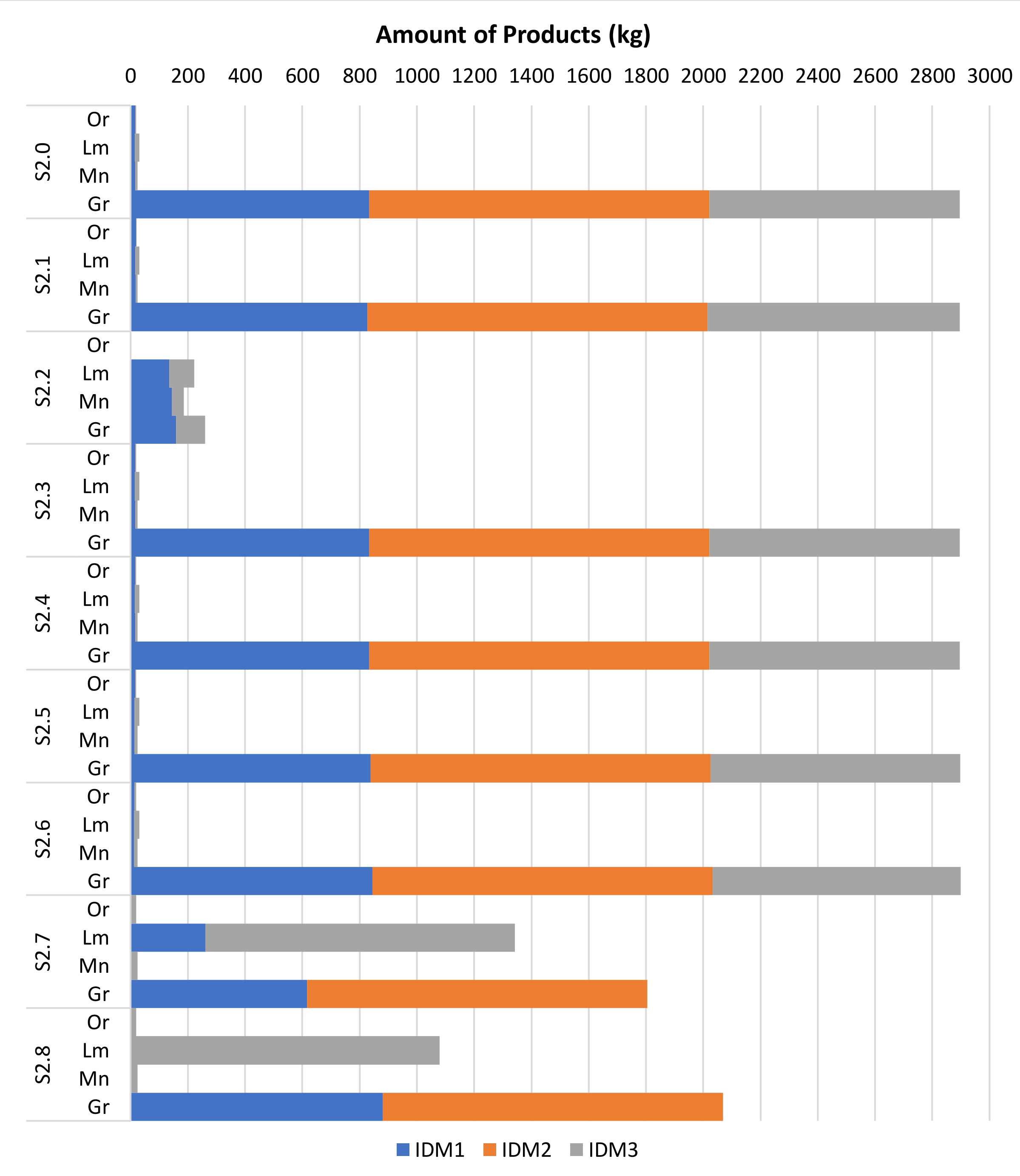

Figure 5. Product Mixes in The Cases Examined for Scenario 2 (Or: Orange, Lm: Lemon, Mn: Mandarin, Gr: Grapefruit, IDM: Heat Exchanger)

The revenue amounts in the cases examined in scenario 2 are given in Figure 6. Accordingly, when the quality of the product increases, the amount of earnings increases. It also shows that if the desired quality is not achieved, the products will not be in demand.

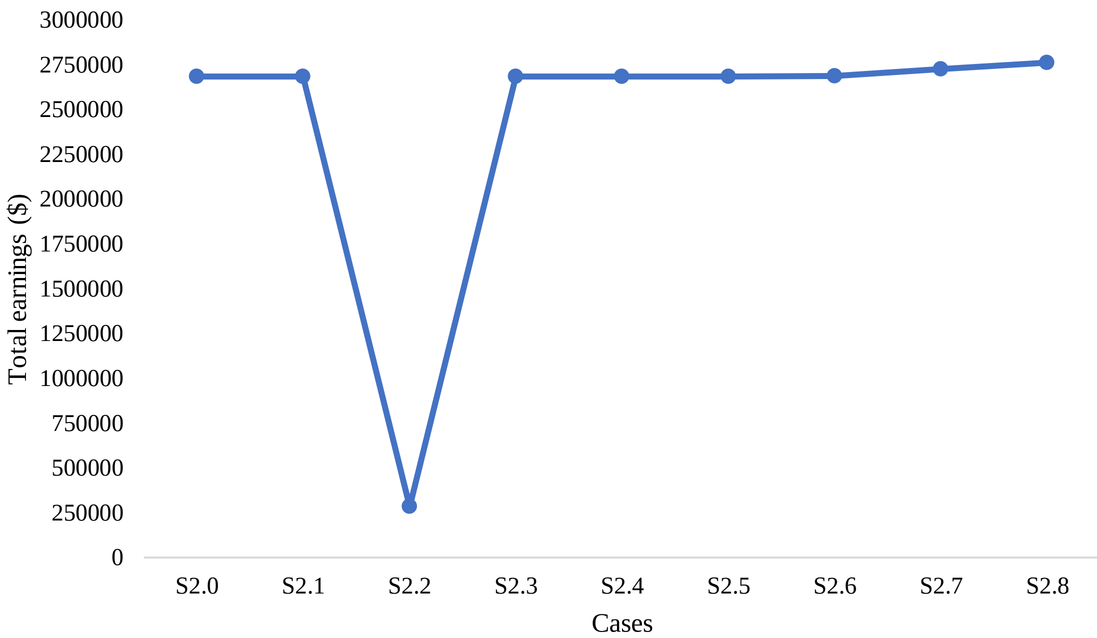

Figure 6. Amounts of earnings for the cases in scenario 2

Finally, in case the quality values of the demanded products increase, the demand meeting capacity and product mixes of the company are examined in scenario 3. In this section, 12 different cases that can be seen in Table 9 are discussed.

Table 9
Cases Examined in Scenario 3

Scenarios	Examined cases
S3.0	The desired product quality in the market does not change
S3.1	Demanding 10% quality improvement for the 1st product
S3.2	Demanding 20% quality improvement for the 1st product
S3.3	Demanding 30% quality improvement for the 1st product
S3.4	Demanding 10% quality improvement for the 2nd product
S3.5	Demanding 20% quality improvement for the 2nd product
S3.6	Demanding 30% quality improvement for the 2nd product
S3.7	Demanding 10% quality improvement for the 3rd product
S3.8	Demanding 20% quality improvement for the 3rd product
S3.9	Demanding 30% quality improvement for the 3rd product
S3.10	Demanding 10% quality improvement for the 4th product
S3.11	Demanding 20% quality improvement for the 4th product
S3.12	Demanding 30% quality improvement for the 4th product

The desired quality levels were achieved in all cases except for the two cases. As can be seen in Figure 7, the required quality could not be achieved in S3.3 and S3.9 cases, so a feasible solution could not be obtained in the model. In the other cases examined, the machines where the products are produced, and the product quantities have not changed. Scenario 3 showed that the majority of the required quality enhancement on customer demand was met by IDM machines, but only the 30% quality enhancement demands for products 1 and 3 could not be met.

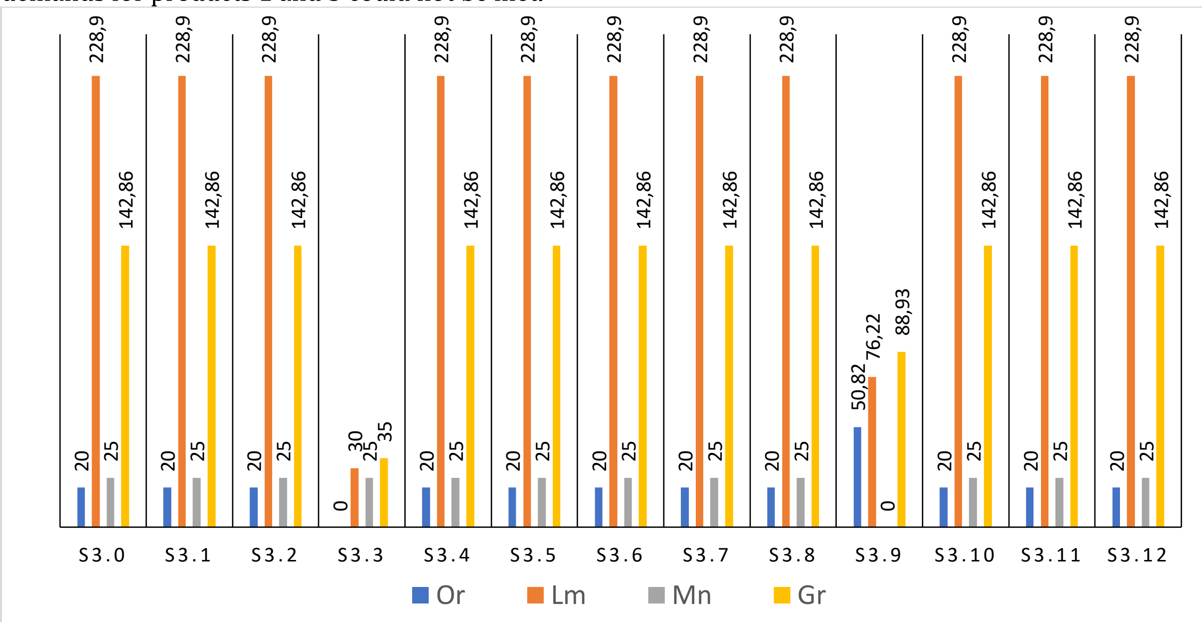

Figure 7. Product Mixes in The Cases Examined for Scenario 3 (Or: Orange, Lm: Lemon, Mn: Mandarin, Gr: Grapefruit)

5. Conclusions

As a result of the analysis made for the company POLIMAG, 90.237 tons of orange nectar, 80 tons of lemon nectar, 55.556 tons of mandarin nectar, and 80 tons of grapefruit nectar should be produced to reach the break-even point. The most important constraint in these productions was observed as the demand constraint and the two products were produced in quantities to meet the maximum demand. Another important constraint was observed as the quality constraint.

With the AHP method, the properties with the highest quality weight were determined as HMF content, bioactive compound content, sensory properties, and color values, respectively. Quality weight values of IDMs differed according to citrus used as raw material. Quality criteria affect the amount produced, type of nectar, and IDM usage rates. It is seen that IDM2 has never been used in the analyses. This situation not only reduces production efficiency but also reduces the lifetime of the other two machines. In addition, using the IDM2 in case of an increase in demand may cause the quality desired by the customer to not be achieved. Maintenance of inefficient machine resources to ensure sufficient quality will increase machine efficiency and product quality.

In the study, the product mix is determined to reach the breakeven point as quickly as possible. In addition, the product mix that obtained the maximum profit was found and the production tendency was followed. In the future, new models with more than one purpose can be used to evaluate resources with idle usages such as bottleneck constraints or IDM2 machines, and studies that can positively affect business management can be carried out.

Considering the scenarios examined in the study, it can be said that the quality criteria of the products change the production efficiency and sales amounts. Considering the quality criteria in the product mix problem gives an idea about not only the products and their quantities that will give maximum profit but also the necessary cautions to be taken to balance the changes in the product quality. In addition, the study has shown how much the existing production system can adapt to changes in consumer demands.

There are some limitations to applying the proposed method. The evaluation of the criteria in the study was made by a limited number of experts and researchers working in different companies in the field of fruit juice quality. Evaluation of the criteria is generally based on experience and observation, not on definitive judgements. Therefore, despite the consistency rates of the evaluations made with the AHP method, uncertainty may remain in the evaluation. In future studies, fuzzy logic and different weighting methods can be used to minimize uncertainties and increase the sensitivity of the study. In addition, to make a more accurate comparison, the number of evaluators can be increased.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Authors' contributions

All authors contributed to the study's conception and design. The first draft of the manuscript was written by Adem Erik and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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