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Enzyme-Aided Treatment of Fruit Juice: A Review

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Abstract.
Enzymatic treatment is a common method of fruit juice production that facilitates juice extraction from plant cells. The choice of enzyme depends on the fruit composition. Pectinase and cellulase are the most popular enzymes while amylase remains less wide-spread. For some raw materials, enzymatic procedures are more efficient than mechanical comminution or thermal processing. The fruit juice industry uses enzymes for streamlining. Enzymes maximize juice extraction from raw materials and improve such processes as pressing, solid settling, and solid removal. Juices that underwent enzymatic treatment are clear and, as a result, more aesthetically appealing to consumers.

The review covered the most recent and influential publications on the enzyme treatment of fruit juices (2000–2021). The list of enzymes included pectinase, cellulase, and amylase. The research included the factors that affect the juice fermentation process, i.e., hydromodule, enzyme concentration, incubation time, temperature, and enzyme combination. The methods included data extraction, data analysis, and data compilation, as well as literature search and screening.

The review focuses on the effects that individual parameters have on specific responses, e.g., yield, viscosity, total soluble solids, acidity, turbidity, clarity, pigment concentration, phenolic content, color, and solids. A greater enzyme concentration, incubation time, and temperature decrease the viscosity of juice and turbidity but cause color changes. If used in different combinations and at different concentrations, enzymes boost the production of bael pulp, banana, sapodilla, durian, pawpaw, grape, white pitaya, and water melon juices. A longer incubation period improves the production of bael pulp, citron, date, and pawpaw juices. However, higher incubation temperatures seem to have no positive effect on the juice yield. Cellulases, pectinases, amylases, and their combinations are able to produce more fruit juice of higher quality with a more favorable time-temperature combination of incubation.

The optimal enzyme concentration, incubation time, and temperature can increase the juice yield. Therefore, enzymatic treatment is an effective method that ensures favorable properties of the finished product.

Keywords. Enzyme, fruit juice, incubation time, incubation temperature, viscosity, color

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Применение ферментов при выработке фруктового сока: обзор

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Аннотация.
Обработка сырья ферментами – распространенный метод производства фруктовых соков, способствующий наиболее полному извлечению сока из растительных клеток. Для некоторых видов сырья ферментативные процессы оказываются более эффективными, чем механическое измельчение или термическая обработка. Выбор конкретного фермента зависит от состава фруктов. Чаще всего в пищевой промышленности используются пектиназа и целлюлаза, реже – амилаза. Использование ферментов в технологическом процессе способствует рационализации производства фруктовых напитков. Ферменты способствуют максимальному извлечению сока из сырья и позволяют оптимизировать такие процессы, как отжим, отстаивание и удаление твердых частиц. Соки, прошедшие ферментативную обработку, более прозрачны и обладают большей потребительской привлекательностью.
В обзор включены актуальные и авторитетные научные публикации по ферментативной обработке фруктовых соков (2000–2021 гг.). В список ферментов для поиска вошли пектиназа, целлюлаза и амилаза. Настоящий обзор суммирует такие факторы, влияющие на процесс производства фруктового сока, как гидромодуль, концентрация фермента, время инкубации, температура и комбинация ферментов. В качестве научных методов были использованы поиск и скрининг научной литературы, извлечение данных, их анализ и компиляция.
Основное внимание в обзоре уделяется тому, как отдельные технологические параметры влияют на результат производственного процесса: выход сока, вязкость, общее количество растворимых твердых веществ, кислотность, примеси, прозрачность, концентрацию пигмента, содержание фенолов, цвет и т. д. Более высокая концентрация фермента и температура, а также более длительный период инкубации способны уменьшить вязкость сока и сделать его более прозрачным, но они вызывают изменение цвета. Оптимальная комбинация и концентрация ферментов способны повысить выработку сока из мякоти баиля, банана, саподиллы, дуриана, папайи, винограда, белой питайи и арбуза. Более длительная продолжительность инкубации улучшает производство сока из мякоти баиля, цитрона, фиников и папайи. Более высокие температуры инкубации не оказывают положительного влияния на выход сока. Целлюлазы, пектиназы, амилазы и их комбинации приводят к выработке большего объема фруктового сока и способствуют повышению его качества, если технологический процесс предусматривает оптимальное сочетание температурного режима и продолжительности инкубации.
Оптимальная концентрация фермента, продолжительность инкубации и температурный режим увеличивают объем производства сока. Этот факт доказывает, что ферментативная обработка – эффективный метод производства сока, обеспечивающий готовый продукт максимально высокого качества.

Ключевые слова. Фермент, фруктовый сок, время инкубации, температура инкубации, вязкость, цвет

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Introduction

Enzymes have been widely applied in the food industry, where they facilitate the process of juice extraction from plant cells [1, 2]. Modern science offers novel enzymes with a wide range of uses, specificity, and new application areas [3]. When enzymes first became part of the fruit juice industry, they boosted the yield and quality [4]. Enzymes are biological catalysts that are widely used in fruit juice production, winemaking, and brewing. Pectinases, cellulases, amylases, proteases, etc., allow juice producers to achieve the high production volume required by the market [5]. Recent studies focus on optimizing the enzyme-assisted juice extraction process based on the quality factors of the final product [6].

Fruit juices contain colloids, e.g., pectin, cellulose, hemicellulose, lignin, and starch. Pectinase treatment is a common practice aimed at degrading pectin [7]. Table 1 summarizes the application of enzymes in the fruit juice industry. Enzymic treatment increases the juice yield and results in more transparent final products, especially in grape, apple, pear, and orange juices. Enzymes degrade the cell walls of fruit mash, resulting in a lower juice viscosity and a higher juice yield. Enzymes are known to facilitate the release of flavors, enzymes, polysaccharides and proteins from fruit juices [8]. Enzyme treatments provide a better filtration rate and a clearer finished product, which is regarded as a better quality indicator. In addition, enzymes improve cloud stability and texture in fruit pulp. In some cases, cellulase improves the juice yield and color properties.

Table 1 demonstrates that pectinase have been the most popular research object so far. Less popular enzymes include cytolase and cellulase [9]. Pectinase and cellulase improve the general fruit juice quality by yielding more soluble solids and juice particulates. Chen *et al.* stated that enzyme concentration and incubation condition, i.e., temperature and time, affect the pectic hydrolysis [10].

Study objects and methods

This review concentrated on such enzymes as pectinase, cellulase, and amylase in fruit juice production. The list of factors included hydromodule, enzyme concentration, incubation time, temperature, and enzyme combination that affect the fermentation process of

Table 1. Variables used in the enzymatic treatment of fruit juices

Таблица 1. Переменные, используемые при ферментативной обработке фруктовых соков

Sample	Part/Condition	Enzyme/Enzyme trade name	Variables			Responses	References
			Enzyme concentration/Dose	Temperature, °C	Time		
Acai	Juice	Citrozyme-Ultra L	0.01–0.2%	45	15–60 min	Clarity, color, pH, titratable acidity, total soluble solids, reducing sugar, vitamin C	[11]
Apple	Juice	Pectinex® Clear	10 U	40–50	60 min	Clarification, turbidity, viscosity, total phenols, antioxidant activity	[12]
Apricot	Pulp	Pectinase	0–1.2%	30–50	5	Juice yield	[2]
Bael	Pulp	Pectinase	0.64–7.36 mg/5 g pulp	28.18–61.82	97.5–652.5 min	Juice yield, viscosity, clarity	[13]
Banana	Juice	Pectinase	5–10%	25–40	50–80 h	Polygalacturonase activity, clarity, acidity, reducing sugar	[14]
Blueberry	Juice	Pectinex® BE Colour	10 U	4–50	60 min	Viscosity, turbidity, degree of clarification, antioxidant and total phenolic content	[12]
Carambola	Juice	Pectinex® Ultra SP-L	0.10%	30–50	0.3–1.7	Turbidity, clarity, viscosity, color	[15]
Plum	Juice	Pectin methyl esterase and polygalacturonase	0.05 g/kg	50	120 min	Yield (96.8%)	[16]
Cherry	Juice	Pectinase	0–0.5% v/v	50	1 h	Turbidity	[17]
Date	Pulp	Pectinase, Cellulase	50 U, 5 U	50	120 min	Total soluble solids, polysaccharide, pH, total nitrogen, ash, total phenolic content, turbidity, sensory, color	[18]

Continuation of table 1

Sample	Part/ Condition	Enzyme/ Enzyme trade name	Variables			Responses	References
			Enzyme concentration/ Dose	Temperature, °C	Time		
Durian	Juice	Pectinex® Ultra SP-L	0.10%	38.5	3	Juice yield, total soluble solids, pH, viscosity, color, sensory	[19]
Grape	Juice	Pectinase	1.5–3 mL 100/kg	50 and 60	1 h	pH, total soluble solids, titratable acidity, turbidity, color intensity, juice yield, organic acid	[20]
Grapefruit	Peel	Pectinex® Ultra SPL, Cellulase 1.5L	1–15 and 1–10 mg/g	45	–	Yield of sugar, dry matter	[21]
Guava	Mash	Cellulase	0.048–0.132% (w/w)	50	11.7–68.3 min	Extraction yield, total sugar, ascorbic acid, total phenolic, antioxidant activity	[22]
Lemon	Juice	Pectinase	0–1200 U/L	25–50	0–90 min	Dry matter, protein, ash, total phenolic content, turbidity, viscosity, color, clarity, pH, sugar	[23]
Litchi	Pulp	Pectinase	100–500 ppm	40	2	Total soluble solids, titratable acidity, color, sugars, ascorbic acid	[24]
Mosambi	Juice	Pectinase	0.0004% w/v	–	–	Color, clarity, total soluble solids, acidity, pH, density	[25]
Passion fruit	Juice	Pectinex® 3X L	1 mL/L	50	90 min	Turbidity, color, total soluble solids, viscosity	[26]
Peach	Juice	Pectinex® AFPL3, Ultra SP WOP	240–1200 ppm	18–45	30–150 min	Viscosity, pulp decrease	[7]
Pineapple	Juice	Cellulase, pectinase, hemicellulase	25–150 mg/100 mL	35–55	210–540 min	Juice yield, clarity, viscosity,	[27]
Pineapple	Juice	Xylanase, pectinase, cellulase	0–3%	37	270 min	Yield, clarity	[28]
Pome-granate	Juice	Pectolytic enzyme	0–15 µL/L	25	120 min	Antioxidant, juice yield, color, total soluble solids, betacyanin content	[29]
Red pittaya	Juice	Pectinex® Ultra SP-L, Pectinex® CLEAR	0.01–0.1%	30–50	20–100 min	Proximate, vitamin C, total phenolic content	[30]
Sapodilla	Juice	Pectinex® 3X L	0.03–0.10%	30–50	30–120 min	Turbidity, clarity, viscosity, color	[31]
Water-melon	Juice	Masazyme	0.01–0.1% (w/w)	30–50	20–120 min	Juice yield, total dissolved salts, viscosity, turbidity, cloud stability, lightness	[32]
White pittaya	Juice	Pectinex® Ultra SP-L	0.01–0.1%	30–50	20–100 min	Yield, viscosity, clarity, color	[33]

fruit juice. The processing approach made it possible to compile the most recent reviews and research papers on the enzyme treatment of fruit juices (2000–2021). The methods included data extraction, data analysis, and data compilation, as well as literature search and screening.

Results and discussion

Enzymes in juice production. ***Pectinase.*** Pectolytic enzymes, or pectinases, hydrolyze pectic substances. Fungi used to be the main source for commercial production of pectinases [34]. Pectinolytic enzymes are classified into two main groups: esterase and depolymerases. Esterase affects pectic substances by hydrolysis. Depolymerase happens via two mechanisms, namely hydrolysis and trans-elimination lysis [34].

Pectinex® Ultra SP-L enzyme (Novozymes, Denmark) was described as early as in 1996 as a means of mash enzyme preparation [35]. It had both pectolytic activities, including polygalacturonase, pectinlyase, pectinesterase, etc., as well as hemicellulose, cellulase, protease and amylase galactosidase, chitinase, transgalactosidase, etc. [15]. Pectinex® Ultra SP-L was reported to have a polygalacturonase activity of 26 000 U/mL at ≤ 50°C and pH 3.5–6.0 [36]. On the other hand, Wilkins *et al.* reported that Pectinex® Ultra SP-L exhibited a pectinase activity of 233 IU/mg [21].

The major industrial application of pectinases is fruit juice extraction and clarification (Table 1) [34]. Girijesh *et al.* employed pectinase enzyme to extract kendu (*Diospyros melanoxylon* Roxb.) juice, an underused seasonal fruit that grows in India and possesses various medicinal and nutritional qualities [6]. Pectinases have been used to clarify apple, kiwi, tangerine, pineapple, sapodilla, and carambola [15]. Several other purposes of pectolytic enzymes involve liquefaction, maceration, and cloud stabilization [35]. Pectolytic liquefaction caused qualitative and quantitative changes in tropical fruit compounds and increased the volume of carotenoids released into juice [37].

Cellulase. Cellulases are a group of enzymes that catalyzes the bioconversion of cellulose into soluble sugars and glucose. These enzymes are produced by bacteria, fungi, insects, and mollusks. Cellulase components, such as endo-1,4-β-D-glucanase, exo-1-,4-β-D-glucanase, and β-glucosidase, are generally produced by fungi, bacteria, and actinomycetes, either separately or as a complex. Cellulase is produced by *Trichoderma reesei*. It can be used to break down cellulosic materials, increase yield, and reduce the viscosity of soluble cellulosic substrates. Wilkins *et al*. stated that Celluclast® 1.5 L had a cellulase activity of 0.126 FPU/mg protein [21]. Cellulases are used in a variety of industries, including food industry, catering, food supply, and food preservation. Cellulases tenderize fruits, clarify fruit juices, decrease roughage in dough, hydrolyze roasted coffee, extract tea polyphenols and essential oils from olives, and improve food flavor and taste [38].

Food industry uses cellulases to extract or clarify fruit juices. Cellulases also remove cell walls, thus facilitating the release of flavors, enzymes, polysaccharides, and proteins. According to Abdullah *et al.*, cellulase outperformed tannase in cashew apple juice extraction by 4.69% [39]. In the enzymatic extraction of sugar from date fruit, the optimal conditions for the cellulolytic enzyme included 58°C, pH 5.5, and 0.015% concentration [40].

Amylase. Amylases are one of the oldest and most important commercial biocatalysts, accounting for over 30% of the worldwide enzyme market. They find widespread commercial use in the starch processing sector, where they facilitate starch liquefaction and saccharification. Other spheres of application include baking, pulp production, paper industry, fruit juice clarification, detergents, textile desizing, and distilling [41]. Amylases have been used to process fruits that contain starch: they hydrolyze the raw material into glucose forms. This method prevents retrogradation and post-bottling haze formation, which results in a better clarification and filterability of some fruits, e.g., unripe apple [35].

Lee *et al.* treated banana juice with amylase to obtain starch hydrolysis before treating it with Pectinex® Ultra SP-L [42]. Will *et al.* added Fructamyl HT amylase (80 mL/t) into apple juice to avoid gray and foggy shade, a color defect that resulted from starch retrogradation [43].

Combinations of enzymes. Previously, scientists focused on single enzymes. Recently, scientific attention has shifted into the direction of more effective enzymic combinations. For instance, Padma *et al.* used multiple enzymes (pectinases, amylases, and cellulases) to clarify apple juice [44]. Borchani *et al.* reported the optimal treatment for prickly pear syrup using 5 U cellulase and 20 U pectinase [45].

Handique *et al.* found that 0.34% cellulase and 0.35% pectinase served as optimal conditions for banana juice extraction [46]. On the other hand, Heffels *et al.* used four commercial pectinolytic and two cellulolytic enzymes for bilberry juice extraction [47]. For palm juice extraction, the optimal ratio of pectinase:cellulase enzyme was 1:0.75 (w/w) while for blueberry juice it was 1:1 [48, 49]. In addition, Navarrete-Solis *et al.* applied response surface methodology to jackfruit juice hydrolysis, which was at its best at 1% cellzyme and pectinex enzyme treatment [50].

The results may differ from fruit to fruit. For example, when Chang *et al*. applied Pectinex® Ultra SP-L, Celluclast® 1.5L, and Fungamyl® 800 L to soursop in single or combination, Pectinex® Ultra SP-L proved to be the primary liquefaction enzyme to yield the best puree samples [51]. Bora *et al.* found out that pectinase improved banana juice yield, compared to cellulase and their combinations [52].

Effect of hydromodule on fruit juice fermentation. Table 2 shows different applications of enzymes in liquefaction or clarification of fruits. Clarification may need numerous prior extraction stages, including hot, cold, and enzymatic extraction, to maximize the fruit juice yield. The enzymatic stage proved to be the one with the highest juice recovery yield when compared to the previous two preparatory processes [53]. Water is commonly added to aid in the extraction of fruit juice from pulp. A water to pulp ratio of 1:1 facilitated the enzyme maceration of soursop and yielded more juice from the pulp. Al-Hooti *et al.* used a higher pulp to water ratio of 1:2–1:4 to homogenize date pulp and facilitate juice extraction [9]. Norjana and Noor Aziah utilized a ratio of 1:2 (w/v) to facilitate juice extraction from durian pulp [19].

Table 2. Extraction of fruit juices with different water percentage

Таблица 2. Экстракция фруктовых соков с разным процентным содержанием воды

Sample	Sample:water ratio/percentage	References
Banana pulp	1:2	[14]
Açaí juice	30% (w/v)	[11]
Apricot, plum, mango	100 mL/kg mL	[2]
Citron waste	2:3	[54]
Date pulp	1:3	[18]
Grape pomace	1:5	[55]
Pitaya pulp	1:1	[56]

Factors that affect the properties of enzyme-treated fruit juice. ***Enzyme concentration.*** Pectinase can hydrolyze plant cell walls, causing carotenoid release from plant cells [37]. Pectinase increased the yield, soluble solids content, and clarity of asparagus juice [10]. Chauhan *et al.* also reported an increase in the total soluble solids in juices compared with pulp [2].

Table 3 illustrates the effects of enzyme concentrations on the properties of fruit juices. Sin *et al.* concluded that the enzyme concentration was the most crucial factor for sapodilla juice [31]. The yield of durian juice treated with 0.05% Pectinex® Ultra SP-L increased by 35%. Mango showed a 70–80% reduction in viscosity after pectinase liquefaction, which increased juice recovery and soluble solids.

A greater enzyme concentration resulted in a larger amount of positively charged protein. This effect reduced the electrostatic repulsion between cloud particles, and, in turn, caused aggregation of larger particles. However, these particles eventually settled down [58]. According to Nur Aliaa *et al.*, it is polysaccharides, e.g., pectin or starch, that are responsible for cloudy juice [33].

Table 3. Effect of enzyme concentrations on fruit juice properties

Таблица 3. Влияние концентрации фермента на свойства фруктового сока

Sample	Enzyme concentrations	Yield	Viscosity	Total soluble solids	pH	Titratable acidity	Ascorbic acid	Turbidity	Clarity	Pigment concentration	Phenolic content	Color	Dry matter/Alcohol insoluble solids	References
Bael pulp	0.64–7.36 mg/25 g pulp	+ve	-ve	–	–	–	–	–	+ve	–	–	–	–	[13]
Banana juice	0–0.2%	+ve	–	+ve	–	–	–	–	+ve	–	–	–	–	[57]
Carambola juice	0.01–0.1% v/v	–	-ve	–	–	–	–	-ve	-ve	–	–	*L**+ve	–	[15]
Durian juice	0–0.1%	+ve	-ve	+ve	-ve	–	–	–	–	–	–	*L**-ve *a**-ve *b**-ve	–	[19]
Grape juice	1.5–3.0 mL100/kg	+ve	–	NS	NS	NS	–	-ve	–	–	–	NS	–	[20]
Guava juice	0.16–0.84 mg/g	–	-ve	–	–	–	+ve	–	+ve	–	–	*L**+ve	–	[58]
Pawpaw juice	0–40 mg	+ve	-ve	–	–	–	–	–	–	–	–	–	–	[59]
Pineapple juice	25–150 mg/100 mL	–	-ve	–	–	–	–	–	+ve	–	–	–	–	[27]
Pomegranate juice	0.5–5 µL/mL	–	–	–	–	–	–	–	-ve	–	+ve	–	–	[60]
Sapodilla juice	0.03–0.1%		-ve	–	–	–	–	-ve	-ve	–	–	*L**+ve	–	[31]
Watermelon juice	0.01–0.15% (w/w)	+ve	-ve	–	–	–	–	–	–	–	–	*L**+ve	+ve	[32]
White pittaya juice	0.01–0.1%	+ve	-ve	–	–	–	–	–	+ve	–	–	+ve	–	[33]

*+ve – positive effect/increases; -ve – negative effect/decreases; NS – no significant effect; – – not reported; *L** – brightness; *a** – +red to -green component; *b** – +yellow to -blue component.

*+ve – положительный эффект/увеличение; -ve – отрицательный эффект/уменьшение; NS – без значимого эффекта; – – данные отсутствуют; *L** – яркость; *a** – +красный, -зеленый; *b** –+желтый, -синий.

Incubation time. Table 4 summarizes the effects of incubation time on the properties of fruit juices. Tadakittisarn *et al*. optimized incubation time to increase the yield during banana juice liquefaction [57]. They treated banana juice with 0.15% pectinase enzyme at 50°C for 120 min and obtained a yield of 59.44–65.29%, which exceeded that in the control sample (43.2%).

Norjana & Noor Aziah increased the yield of durian juice by 35% by treating the durian pulp with 0.05% pectinase for 3 h [19]. Bhat treated fruit pulp with enzymes and obtained a greater yield and a better performance [1]. Not only did this method increase the yield but it also reduced the processing time and improved the extraction of fruit compounds.

Viscosity is usually considered as an important physical characteristic related to the quality of liquid foods. Enzymes decreased viscosity due to their hydraulic action on cellulose and pectin present in the juice [31]. Domingues *et al.* found that a shorter treatment time did not reduce viscosity in passion fruit juice after 30 min of incubation [26]. In the production of banana juice, a longer treatment time was associated with an increase in filterability and clarity [42]. A longer maceration time also decreased the absorbance [33].

The highest yield of carotenoids was reported after the enzymatic maceration of orange peel. The extraction time was 12, 18, and 24 h. The experiment involved 5-, 10-, and 10-mL pectinase, respectively, per 100 g of wet peel and 0.5 g of cellulase per 100 g of cellulose [63]. Enzymes are known to disrupt cell wall, thus releasing carotenoids that bind with protein. This process prevents pigment oxidation and affects color stability, while solvent extraction causes its dissociation and affects water solubility.

The change in incubation time from 30 to 90 min was the variable that significantly affected turbidity, clarity, viscosity, color, and yield [64]. The L^* value of carambola juice decreased with time and started to increase after 80 min [15]. The increase of incubation time triggered the development of protein-tannin complex. Sin *et al.* tested sapodilla juice and managed to increase its L^* value by raising the enzyme concentration and incubation time [31].

Incubation temperature. Table 5 summarizes the different effects of incubation temperature on the properties of fruit juices. Enzymic incubation can be performed at different temperatures, but the main range is 40–50°C. The incubation temperature fell below 50°C because the high temperature deactivated the enzyme [19].

Chauhan *et al*. increased the yield of apricot, plum, and mango juice by increasing the incubation time, the optimum being 5, 5, and 6 h of incubation, respectively [2]. In terms of clarity, a longer incubation time had a positive effect on the clarity of banana juice [61].

Table 4. Effects of incubation time on fruit juice properties

Таблица 4. Влияние продолжительности инкубации на свойства фруктового сока

Sample	Incubation time	Yield	Viscosity	Total soluble solids	Ascorbic acid	Turbidity	Clarity	Pigment concentration	Phenolic/ Antioxidant	Color	Dry matter/ Alcohol insoluble solids	References
Bael pulp	97.5–652.5 min	+ve	+ve	–	–	–	+ve	–	–	–	–	[13]
Banana juice	20–120 min	–	-ve	–	–	–	+ve	–	+ve		+ve	[61]
Blackberry juice	120 min	–	-ve	–	–	–	–	+ve	–	–	–	[18]
Carambola juice	20–100 min	–	-ve	–	–	+ve	–		–	L^*-ve	–	[15]
Citron waste	20–80 min	+ve	–	–	–	NS	–	–	–	L^*-ve a^*+ve b^*+ve	–	[62]
Date pulp	120 min	+ve	–	+ve	–	–	–	–	–		–	[18]
Guava juice	0.95–11.05 h	–	-ve	–	-ve	–	+ve	–	–	L^*+ve	–	[58]
Pawpaw juice	0–360 min	+ve	-ve	–	–	–	–	–	–	–	–	[59]
Pineapple juice	210–540 h	–	-ve	–	–	–	+ve	–	–	–	–	[27]
Pomegranate juice	30–300 min	–	–	–	–	–	-ve	–	+ve	–	–	[60]
Sapodilla juice	30–120	–	-ve	–	–	-ve	-ve	–	–	L^*+ve		[31]
Watermelon juice	20–120 min	NS	NS	–	–	-ve	–	–	–	L^*+ve	+ve	[32]
White pittaya juice	20–100 min	-ve	+ve		–	–	-ve	–	–	-ve	–	[33]

+ve – positive effect/increases; -ve – negative effect/decreases; NS – no significant effect; – – not reported; L^* – brightness; a^* – +red to -green component; b^* – +yellow to -blue component.

*+ve – положительный эффект/увеличение; -ve – отрицательный эффект/уменьшение; NS – без значимого эффекта; – – данные отсутствуют; L^* – яркость; a^* – +красный, -зеленый; b^* –+желтый, -синий.

Table 5. Effects of incubation temperature on fruit juice properties

Таблица 5. Влияние температуры инкубации на свойства фруктового сока

Sample	Incubation temperature	Yield	Viscosity	Total soluble solids	pH	Titratable acidity	Ascorbic acid	Turbidity	Clarity	Filterability	Pigment concentration	Phenolic/ Antioxidant	Color	Dry matter/ Alcohol insoluble solids	References
Bael pulp	28.18–61.82	NS	+ve	–	–	–	–	–	-ve	–	–	–	–	–	[13]
Banana juice	30–50	–	-ve	–	–	–	–	-ve	-ve	+ve	–	–	–	–	[42]
Carambola juice	30–50	–	NS	–	–	–	–	–	NS	–	–	–	TC+ve	–	[15]
Grape juice	50, 60	NS	–	NS	NS	NS	–	-ve	–	–	–	–	–	–	[20]
Guava juice	36.6–53.4	–	-ve	–	–	–	-ve		+ve				*L**+ve		[58]
Pineapple juice	35–55	–	-ve	–	–	–	–	–	+ve	–	–	–	–	–	[27]
Pomegranate juice	20–50	–	–	–	–	–	–	–	NS	–	–	+ve	–	–	[60]
Watermelon juice	30–50	NS	-ve	–	–	–	–	-ve	–	–	–	–	*L**+ve	+ve	[32]

*+ve – positive effect/increases; -ve – negative effect/decreases; NS – no significant effect; – – not reported; *L** – brightness; TC – total color.

*+ve – положительный эффект/увеличение; -ve – отрицательный эффект/уменьшение; NS – без значимого эффекта; – – данные отсутствуют; *L** – яркость; TC – полный цвет.

Color is an important sensory criterion for fruit juices. Sin *et al.* also stated that the enzyme clarification should be conducted under moderate temperatures because the temperature of 40–60°C facilitated enzymatic clarification in their experiment with sapodilla juice [34]. A higher temperature increased the enzymatic treatment rate in the clarification process when it stayed within the range of 40–60°C, which was below denaturation temperature.

Conclusion

Enzymes improve the sensory profile of fruit juice. The optimization parameters of enzyme treatment include enzyme concentration, incubation time, and temperature. According to this review, different enzymes applied at different concentrations increased the yield of the bael, banana, sapodilla, durian, pawpaw, grape, white pitaya, and water melon juices. A longer incubation time increased the yield of bael, citron, date, and pawpaw juices. However, a higher incubation temperature had no positive effect on any of the abovementioned raw materials. Cellulases, pectinases, and amylases, when applied individually or in combinations, increased the amount of fruit juice produced and improved its quality throughout the incubation process. A correct adjustment of the enzyme concentration, incubation time, and temperature improved the juice yield. The effect differed for each fruit, which means that juice producers have to define the optimal conditions in each particular case. Proper enzyme concentrations, incubation times, and temperatures decreased juice viscosity, reduced turbidity, improved color, and increased yield and total soluble solids. Incubation time had a positive effect on pigment concentration, while a greater enzyme concentration increased the clarity.

Contribution

L.P. Pui reviewed scientific publications, designed the research, and wrote the manuscript. L.A.K. Saleena processed and analyzed the data, reviewed scientific publications, and edited the manuscript.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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Л. П. Пуи – обзор научных публикаций, план исследования, текст статьи. Л. А. К. Салена – обработка и анализ данных, обзор научных публикаций, редактирование текста статьи.

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