Physiochemical changes in sunberry (*Physalis minima* L.) fruit during growth and ripening

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Abstract — Introduction. *Physalis minima* is a widespread, quick-growing and high fruit-yielding annual herb belonging to the family Solanaceae. However, like many other underutilized fruit-bearing plants, *P. minima* is poorly studied and its nutritional potential is unknown. Since the edible sunberry is said to be a rich source of vitamin C, we studied the physiochemical changes during its fruit growth and ripening. **Materials and methods**. The changes in the physiochemical properties, such as pH, total soluble solids, titrable acidity, chlorophylls, carotenoids, carbohydrates (reducing sugars, non-reducing sugars, total sugars and starch), free amino acids, total proteins, total phenols, ascorbic acid, ethylene, and respiration and the activities of hydrolytic enzymes (amylase and invertase), antioxidant enzymes (catalase and peroxidase), and cell wall-degrading enzymes (cellulase, polygalacturonase and pectinmethylesterase), were analyzed in the fruit of sunberry at five sequential stages, *viz.*, the young, premature, mature, preripe and ripe stages. **Results and discussion**. A gradual increase in the pH and total soluble solids occurred throughout the growth and ripening of sunberry fruit, while its titrable acidity increased up to the preripe stage and thereafter declined. A decreasing trend in the chlorophylls occurred simultaneously with an increase in the quantity of carotenoids. As the sunberry fruit proceeded towards ripening, the amount of its total starch decreased, with a concomitant sharp increase in the quantity of its reducing sugars, non-reducing sugars and total sugars. An increase in the quantity of free amino acids, proteins and phenols also occurred during the growth and ripening of the fruit, and the quantity of ascorbic acid increased at the mature stage. Moreover, sunberry fruit also exhibits a climacteric behavior with increased ethylene production and rate of respiration. The specific activity of amylase increased throughout the growth period of sunberry, but that of invertase decreased after maturity until ripening. The catalase and peroxidase enzymes showed higher activity, indicating better radical scavenger properties, while cellulase, polygalacturonase and pectinmethylesterase tended to remain at lower levels. **Conclusion**. The fruit of *P. minima* are nutritive and a rich source of sugars, starch, free amino acids, proteins, total phenols and ascorbic acid. They are metabolically active, showing a high specific activity of hydrolyzing and antioxidant enzymes, while the activity of cell wall-degrading enzymes is relatively low, indicating a better postharvest storage life.

India / *Physalis minima* / fruit / growth / ripening / developmental stages / physicochemical properties

Changements physico-chimiques du fruit de *Physalis minima* L. pendant sa croissance et sa maturation.

Résumé — Introduction. L'espèce *Physalis minima* est largement répandue ; c'est une plante fruitière herbacée annuelle, de la famille des solanacées, à croissance rapide et hauts rendements. Cependant, comme beaucoup d'autres plantes fruitières sous-utilisées, l'espèce *P. minima* est peu étudiée et les qualités nutritionnelles de son fruit sont peu connues. Puisque le physalis comestible est dit riche en vitamine C, nous avons étudié les modifications physico-chimiques qui interviennent au cours de la croissance et de la maturation de son fruit. **Matériel et méthodes**. Les changements de caractéristiques physico-chimiques, tels que le pH, les solides solubles totaux, l'acidité titrable, les chlorophylles, les caroténoïdes, les glucides (sucres réducteurs, non réducteurs, sucres totaux et amidon), les acides aminés libres, les protéines totales, les phénols totaux, l'acide ascorbique, l'éthylène et la respiration, l'activité des enzymes hydrolytiques (amylase et invertase), des enzymes antioxydants (catalase et peroxydase) et des enzymes de dégradation des parois cellulaires (cellulase, polygalacturonase et pectinmethylesterase), ont été analysés dans le fruit de *P. minima* à cinq stades de développement successif : jeune, prématuré, mature, prémûr et mûr. **Résultats et discussion**. Une augmentation progressive du pH et des solides solubles totaux a été observée tout au long de la croissance et de la maturation du fruit, tandis que son acidité titrable augmentait jusqu'au stade prémûr pour ensuite diminuer. Les chlorophylles ont eu tendance à diminuer en même temps qu'augmentait la quantité des caroténoïdes. La quantité totale de l'amidon a nettement diminué avec la maturation du fruit et, de façon concomitante, la quantité des sucres réducteurs, non réducteurs et sucres totaux a augmenté. Une augmentation de la quantité d'acides aminés libres, de protéines, de phénols a eu lieu également au cours de la croissance et de la maturation du fruit de physalis. Par ailleurs, la quantité d'acide ascorbique a aussi augmenté au stade du fruit mûr. En outre, le physalis se comporte comme un fruit climactérique du fait de l'augmentation de sa production d'éthylène et de son taux respiratoire. L'activité spécifique de l'amylase a augmenté tout au long de la période de croissance du fruit, mais celle de l'invertase a diminué après la maturité. Les catalase et peroxydase ont montré une activité accrue, indiquant une meilleure aptitude au piégeage des radicaux libres, tandis que les cellulase, polygalacturonase et pectinmethylesterase ont eu tendance à rester à des niveaux inférieurs. **Conclusion**. Le fruit de *P. minima* est nutritif ; il est une riche source en sucres, amidon, acides aminés libres, protéines, phénols totaux et acide ascorbique. Ce fruit est métaboliquement actif ; il présente une activité spécifique élevée des enzymes hydrolysants et antioxydants, tandis que l'activité des enzymes de dégradation de la paroi cellulaire est relativement faible, indiquant une meilleure aptitude à la conservation après récolte.

Inde / *Physalis minima* / fruit / croissance / mûrissage / stade de développement / propriété physicochimique

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1. Introduction

Physalis, a genus of the family Solanaceae consisting of about 100 species, is mainly distributed in tropical and temperate America, but some of the species have a worldwide distribution [1]. Physalis fruits are nutritious, containing particularly high levels of niacin, carotenoids and minerals [2]. In India, sunberry (*Physalis minima* L.), an annual herb, is wildly distributed. It is a quick-growing and high fruit-yielding plant. Its erect stem possesses ovate, acute, toothed or lobed leaves and solitary pedicellate filiform flowers. The fruit is a berry, which measures about 1.5 cm in diameter and is enclosed in an inflated, bladder-like calyx or husk. It is juicy, mildly astringent and sweet, with a pleasant blend of acid, and tastes like a cherry tomato [3]. The unripe fruit can be cooked as a vegetable [4], while the ripe fruits are eaten as such and used as an appetizer, bitter, diuretic, laxative and tonic [4, 5]. The edible fruit contains about 6% sugars, 2.7% protein, 1.2% ash, 0.6% tannin, 0.5% pectin and is a rich source of vitamin C [6], while the extracts from the plant have shown anticancer activity [7]. The juice of the leaves when mixed with mustard oil and water has also been used as a remedy for earache [5]. In view of these medicinal and nutritional values, now *Physalis* is included in the priority list of many governments' horticulture and fruit export plans. However, it is relatively unknown in importing markets and remains an exotic fruit [8]. Besides, no attention has been paid to the utilization of *Physalis* fruits in food industries and there is little available data in the literature regarding its nutritional properties and industrial utilization. Thus, our study was undertaken with the aim of evaluating the nutritional value related to physiochemical changes associated with growth and ripening of the fruit of *P. minima*.

Figure 1.
Morphological features of the fruit-bearing *Physalis minima* plant.

2. Materials and methods

About 40 to 50 healthy and vigorously growing plants of *Physalis minima* var. *indica* were selected from their natural population growing in the vicinity of the Biosciences Department of Sardar Patel University, India. For each of the presently studied parameters, five to ten fruits were collected from each of these selected plants, during the monsoon period (August–September) of 2008.

The stage of the development of the fruit was decided based on the location of the fruit on the parent plant. While the fruits located on the lower branches mature and proceed towards the ripening stage, the young ones appear on the upper branches. Applying the selection criteria, as modified from Gutierrez *et al.* [9], the fruits were categorized into five sequential growth stages, *viz.*, (i) dark green berry; young stage (ii) green berry; premature stage (iii) light green berry; mature stage (iv) light yellow berry, preripe stage; (v) yellow berry, ripe stage (*figure 1)*. After recording the length, diameter and fresh weight of these fruits, they were subjected to biochemical analyses.

After thoroughly homogenizing 2 g of fruit sample with 25 mL of distilled water, the pH was measured by using a digital pH meter (Model Li 120, Elico), while the titrable acidity of the fruit sample was determined by titrating 10 mL of homogenized sample with 0.1 N NaOH solution; the obtained results were expressed in % citric acid [10].

The juice from sunberry fruits was pooled by pressing them through cheesecloth and using a hand-held refractrometer (Atago Co., Tokyo, Japan) the concentration of its total soluble solids was measured and expressed as a percentage [9].

The quantitative analysis of pigments such as chlorophyll *a*, chlorophyll *b*, total chlorophylls and total carotenoids was carried out as per the previously described methods by Wang *et al.* [11]. The concentration of reducing sugars and non-reducing sugars was determined following the dinitrosalicylic acid method [12], while the anthrone method was followed for the estimation of total soluble sugars and starch [13].

The amount of free amino acids was determined by using the method described by Moore and Stein [14], while the proteins and total phenolic contents were quantified by following the methods of Lowry *et al.* [15]

Table I.
Fresh weight, length, diameter, pH, titrable acidity, total soluble solids and ascorbic acid of *Physalis minima* fruit at its sequential stages of growth and ripening.

Stages of fruit growth and ripening	Fresh weight (g)	Length (cm)	Diameter (cm)	pH	Titrable acidity (%)	Total soluble solids (%)
Young	0.020 ± 0.005	0.5 ± 0.06	0.2 ± 0.05	3.99 ± 0.06	0.46 ± 0.08	2.50 ± 0.01
Premature	0.059 ± 0.004	0.7 ± 0.10	0.3 ± 0.05	4.05 ± 0.06	0.48 ± 0.10	3.10 ± 0.10
Mature	0.199 ± 0.016	0.9 ± 0.10	0.5 ± 0.06	4.94 ± 0.03	0.49 ± 0.09	4.16 ± 0.15
Preripe	0.344 ± 0.024	1.0 ± 0.12	0.7 ± 0.10	5.68 ± 0.06	0.51 ± 0.06	5.13 ± 0.15
Ripe	0.585 ± 0.050	1.1 ± 0.12	0.8 ± 0.12	5.87 ± 0.03	0.47 ± 0.10	6.00 ± 0.10

Mean values ± standard deviation of five samples.

and Bray and Thorpe [16], respectively. Ascorbic acid (vitamin C) content was measured using the 2, 6-dichlorophenol indophenol dye by titration method and the results were expressed as mg·100 g^{-1} [17]. The ethylene evolution and the rate of respiration were measured by using a Gas Chromatograph (Perkin Elmer Autosystem XL) [18].

The specific activities of hydrolyzing enzymes such as amylase and invertase were evaluated as per the methods cited by Devi *et al.* [19] and Mahadevan and Sridhar [20], respectively, while the specific activity of catalase was measured according to the method cited by Devi *et al.* [19]; the method of Mazumdar and Majumder [21] was followed for assessing the activity of peroxidase. The specific activities of cell wall-degrading enzymes such as cellulase, polygalacturonase (PG) and pectin methyl esterase (PME) were assayed according to the procedure described by Sarra and Goukh [22], Zainon and Brady [23], and Hagerman and Austin [24], respectively.

The data presented in this paper is the mean and standard deviation of three replicates for each of the parameters tested; results were subjected to statistical analysis using Duncan's multiple range test (DMRT) [25].

3. Results and discussion

The study of physical changes associated with the sequential stages of growth and ripening of the sunberry fruit revealed that the fresh weight, length and diameter of this fruit increased throughout its growth period (*table I*); the pH increased simultaneously, from 3.99 at the young stage to 5.87 at the ripe stage. Willis *et al.* opined that the change in pH is mainly due to the leakage of organic acids from the vacuole [26]. The titrable acidity (TA) is considered as one of the physicochemical properties which affects both organoleptic and keeping qualities of a product [2].

The concentration of TA content of the currently studied sunberry fruit was found to increase with the advancement of its maturity and reached the peak stage when the fruit attained the preripe stage (0.51%) (*table I*). Moneruzzaman *et al.* reported that half-ripe tomato fruit contains a higher amount of TA as compared with that of fully ripe tomato fruit [27]. Our results showed a lower amount of TA in the ripe sunberry fruit. This might be either due to the degradation of citric acid, which could be attributed to increased activity of citric acid glycoxylase during ripening, or to the reduction in acidity due to its conversion into sugars, and their further utilization in metabolic processes in the fruit. These results are in accordance with those of Doreyappa-Gowda and Huddar, who reported a similar pattern of TA in different varieties of mango fruit [28].

The percentage of total soluble solids (TSS) increased gradually with the advancement of the ripening process of sunberry fruit and the ripe fruit was found to contain the highest quantity of TSS (6.0%), while the lowest TSS (2.5%) occurred in the young

Table II.
Changes in the composition of pigments in the fruit of *Physalis minima* at its successive stages of growth and ripening.

Stages of fruit growth and ripening	Chlorophyll *a*	Chlorophyll *b*	Total chlorophylls	Total carotenoids
	(mg·100 g^{-1})			
Young	3.92 ± 0.02 e	1.14 ± 0.04 d	5.05 ± 0.06 e	0.695 ± 0.011 a
Premature	3.31 ± 0.03 d	1.05 ± 0.07 cd	4.37 ± 0.05 d	0.852 ±0.010 b
Mature	2.66 ± 0.04 c	0.98 ± 0.06 c	3.64 ± 0.03 c	1.545 ±0.013 c
Preripe	1.07 ± 0.02 b	0.43 ± 0.02 b	1.50 ± 0.04 b	1.761 ± 0.020 d
Ripe	0.87 ± 0.04 a	0.29 ± 0.09 a	1.15 ± 0.04 a	2.184 ± 0.040 e

Values of means followed by different letters are statistically significant according to Duncan's multiple range test (DMRT) at the 5% level (n = 3).

fruit (*table I*). Our results are in agreement with those of Tadesse *et al.*, who found that the TSS content increased significantly during fruit ripening of pepper from its green to red-colored stage [29]. The highest amount of TSS is probably due to the increased accumulation of hexose sugar during fruit ripening. These changes are attributable to increasing the sweetness of the fruit.

The quantitative analysis of pigments of sunberry revealed that a significant decrease ($p < 0.05$) occurred in the amount of chlorophyll *a* from 3.92 mg·100 g^{-1} at the young stage to 0.87 mg·100 g^{-1} at the ripe stage (*table II*). A similar trend was also noticed in the quantity of chlorophyll *b* and total chlorophylls. These changes observed in our studies are in agreement with those of Tucker, who reported a decreasing level of chlorophyll during ripening [30]. According to Stanley, the loss of chlorophyll can also be mediated through several processes such as the action of the enzyme chlorophyllase or enzymatic oxidation that produces low-molecular-weight products, which are colorless [31]. Carotenoids constitute the major coloring substances in fruit. In addition, carotenoids have an effect on the nutritive value as they are considered as natural antioxidants and pro-vitamin A [2]. The amount of carotenoids in the fruit of sunberry was found to increase significantly ($p < 0.05$) from the young stage to the mature stage (*i.e.*, 0.695 mg·100 g^{-1} to 2.184 mg·100 g^{-1}, respectively) (*table II*). This finding supports the view of Stanley, who advocated that significant color changes may be mediated in fruits through the degradation of chlorophyll and the exposure of preexisting carotenoids [31].

The increased levels of reducing sugars during fruit ripening are attributed to the breakdown of starch into water-soluble sugars, sucrose and glucose, while the decrease in reducing sugars during storage may be due to further hydrolysis [32, 33]. Besides, a proportional increase in total sugar level also occurs due to increased activity of amylase and other enzymes, resulting in gluconeogenesis and converting starch into sucrose, glucose and fructose [32, 34]. In our studies, both reducing and non-reducing sugars of sunberry fruit exhibited consistency in their quantity, measuring 4.34 mg·g^{-1} and 5.18 mg·g^{-1}, respectively, at the ripe stage (*table III*). In contrast, the amount of starch was found to decrease by 56% during the sunberry growth period (*table III*). Thus, the patterns of carbohydrate content indicate that the young fruit of *P. minima* is a rich source of starch.

Our results revealed that, as the sunberry fruit grows, the amount of total sugars increases until the ripe stage (9.51 mg·g^{-1}) of sunberry fruit, which is statistically also significant, while the young fruit possesses the lowest amount of total sugars (6.62 mg·g^{-1}). Similar results for total sugars have been previously reported in tomato fruit by Moneruzzaman *et al.* [35]. Also, the changes that occur in the quantity of total

Table III.
Changes in the carbohydrate content of *Physalis minima* at its various stages of fruit growth and ripening.

Stages of fruit growth and ripening	Total soluble sugars	Reducing sugars	Non-reducing sugars	Total starch
	($mg \cdot g^{-1}$)			
Young	6.62 ± 0.24 a	2.68 ± 0.21 a	3.93 ± 0.13 a	170.24 ± 14.44 c
Premature	7.02 ± 0.34 a	2.90 ± 0.31 ab	4.12 ± 0.03 b	107.74 ± 6.76 b
Mature	8.10 ± 0.42 b	3.40 ± 0.40 bc	4.70 ± 0.01 c	95.24 ± 3.72 ab
Preripe	8.53 ± 0.23 b	3.50 ± 0.24 c	5.03 ± 0.02 d	99.40 ± 21.15 ab
Ripe	9.51 ± 0.24 c	4.34 ± 0.22 d	5.18 ± 0.05 e	78.57 ± 12.88 a

Values of means followed by different letters are statistically significant according to Duncan's multiple range test (DMRT) at the 5% level. (n = 3).

Table IV.
Changes in the composition of free amino acids, total proteins, total phenols and ascorbic acid of the *Physalis minima* fruit at its various stages of growth and ripening.

Stages of fruit growth and ripening	Free amino acids	Total proteins	Total phenols	Ascorbic acid ($mg \cdot 100\ g^{-1}$)
		($mg \cdot g^{-1}$)		
Young	4.51 ± 0.93 b	17.20 ± 3.80 a	2.92 ± 0.56 a	36.22 ± 1.54 a
Premature	3.05 ± 0.88 a	17.83 ± 1.80 a	5.67 ± 1.57 bc	43.34 ± 1.33 b
Mature	3.92 ± 0.34 ab	29.35 ± 2.73 b	6.06 ± 0.45 c	46.67 ± 5.78 b
Preripe	4.61 ± 0.66 b	37.08 ± 4.74 c	7.53 ± 0.30 d	34.23 ± 1.68 a
Ripe	7.56 ± 0.68 c	50.25 ± 5.73 d	4.89 ± 0.67 b	31.78 ± 1.02 a

Values of means followed by different letters are statistically significant according to Duncan's multiple range test (DMRT) at the 5% level (n = 3).

sugars, reducing sugars and starch are in accordance with the findings of Patel and Rao [36]. Rana and Rana also reported recently a steady increase in the quantity of total sugars and reducing sugars during the period of growth and ripening of kiwi fruit [37]. Likewise, an increase in the amount of reducing sugars (*i.e.*, glucose and fructose) and degradation of starch was observed in the currently studied sunberry fruit, with a gradual increase in its non-reducing sugar (sucrose). Thus, our results are in agreement with the findings of Dalal *et al.*, who reported that reducing sugars often increase steadily throughout growth and maturation in both climacteric and non-climacteric fruits [38].

The quantitative analysis of total free amino acids in the fruit of sunberry showed a 33% decrease from 4.51 $mg \cdot g^{-1}$ at the young stage to 3.05 $mg \cdot g^{-1}$ at the premature stage, but subsequently, there was an increase to 7.56 $mg \cdot g^{-1}$ at the ripe stage (*table IV*). According to Frankel *et al.*, the early reduction in the quantity of total free amino acids may be due to their incorporation into proteins required for the synthesis of various ripening enzymes and subsequently their utilization may also decline, causing an increase in their quantity at the later stages [39].

Proteins are known to be involved in the metabolism during growth and ripening of fruits. Hulme *et al.* [40] and Diley and Hulme [41] stated that the synthesis of proteins is stimulated during the early stages of fruit growth and development. Likewise, our results regarding the sunberry fruit also exhibited a three-fold increase in the quantity of total proteins from 17.20 $mg \cdot g^{-1}$ at the young stage to 50.25 $mg \cdot g^{-1}$ at the ripe stage (*table IV*).

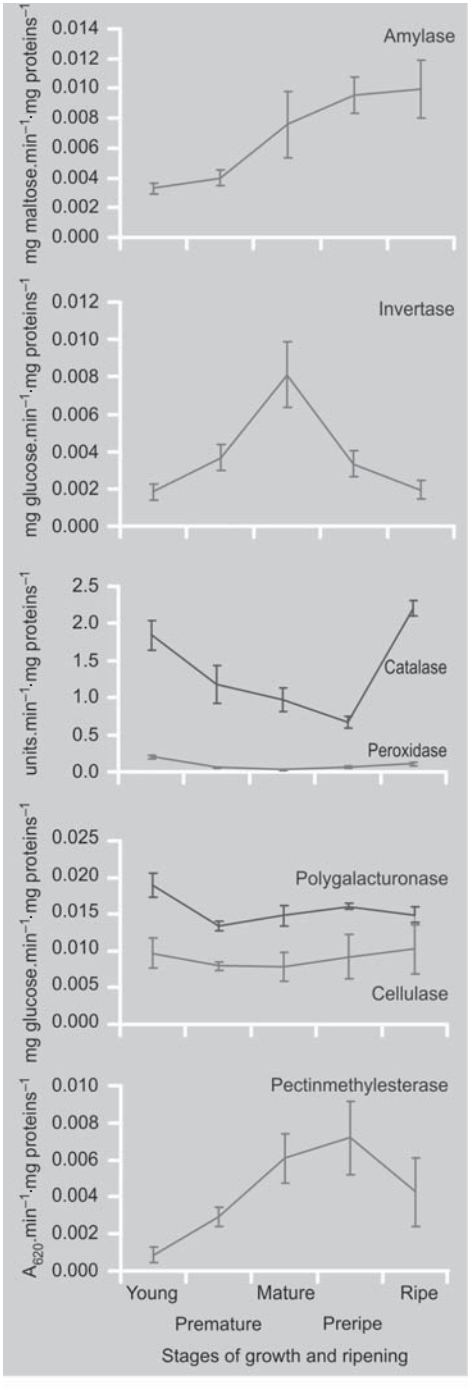

Figure 2.
Specific activity of enzymes in *Physalis minima* fruit at different stages of growth and ripening.

Phenolic compounds are important components of many fruits, vegetables and beverages, in which they contribute to color and sensory properties such as bitterness and astringency [42]. Phenols, which are known as the substances of the aromatic compounds in fruits, peaked in preripe sunberry fruit, with a subsequent decline at the ripe stage (*table IV*). Thus, our results support the opinions of Kumar and Goswami that the significant accumulation of total phenols in the early stages acts as a protection mechanism for the phytohormones (auxins, gibberellins and cytokinins), which play an important role in cell division and cell enlargement [43]. However, phenols of sunberry eventually exhibit a declining trend, which was reported earlier by Kumar and Goswami [43].

Ascorbic acid is a powerful antioxidant and an important part of human food. It helps to save the human from many serious diseases and scavenges the reactive oxygen species (ROS) produced in the body [44]. The currently studied sunberry fruit showed significantly varied amounts of ascorbic acid at different maturity levels, with the highest contents at the mature stage (46.67 mg·100 g^{-1}) and the lowest (31.78 mg·100 g^{-1}) at the ripe stage (*table IV*). Our results further reveal that decrease in ascorbic acid occurs with the advancement of ripening of sunberry fruit. Similar results were reported by Moneruzzaman *et al.* in tomato fruit [27].

In climacteric fruits, ethylene closely coordinates a number of catabolic and anabolic events during ripening, resulting in rapid perishability. Evaluation of ethylene levels in sunberry revealed an almost twofold increase when the fruit attains the ripe stage (*table V*). Sunberry displays a unique ripening pattern by involving an impressive increase in ethylene production rates, similar to the behavior of goldenberry fruit [45]. Our study shows that the rate of respiration in the sunberry fruit during its young stage is 0.35 µL·kg^{-1}·h^{-1}, but subsequently the respiration rate declines to 0.32 µL·kg^{-1}·h^{-1} at the premature stage. However, with the onset of ripening, the level of respiration increases by 38%, reaching 0.52 µL·kg^{-1}·h^{-1} (*table V*). Like other climacteric fruits, sunberry fruit also demonstrates a climacteric rise in the rate of respiration and increase in ethylene production.

Amylase and invertase are the hydrolytic enzymes with an active role in the conversion of the storage material such as starch

Table V.
Changes in the levels of ethylene (C_2H_2) and rate of respiration (CO_2) of *Physalis minima* at its various stages of fruit growth and ripening.

Stage No.	Stages of fruit growth and ripening	Levels of ethylene	Rate of respiration
		($\mu L \cdot kg^{-1} \cdot h^{-1}$)	
1	Young	0.25	0.35
2	Premature	0.28	0.32
3	Mature	0.35	0.36
4	Preripe	0.38	0.54
5	Ripe	0.48	0.52

into sugars. Amylase, which participates in starch degradation, shows its varying activity patterns during ripening. The specific activity of amylase of sunberry exhibited a significant increase from the young stage (0.003 mg maltose·min^{-1}·mg^{-1} protein) to the ripe stage (0.009 mg maltose·min^{-1}·mg^{-1} protein) (*figure 2*). The fruits of banana [46] and apple [47] are reported to have a similar kind of increase in the activities of their starch-degrading enzymes.

The specific activity of invertase of sunberry increased initially from 0.001 mg glucose·min^{-1}·mg^{-1} protein at the young stage to 0.008 mg glucose·min^{-1}·mg^{-1} protein at the mature stage and, subsequently, declined to lower levels, until ripening (*figure 2*). The statistical analysis of the data obtained regarding this parameter indicates that the changes in the activity of invertase are insignificant. Dilley and Hulme also reported a similar kind of increased invertase activity in different fruits during their early stages of fruit development but with an ultimate decline in it [41], while Leopold and Kriedemann suggested that these hydrolytic changes may lead to the formation of sugars [48].

Catalase catalyzes the breakdown of H_2O_2 into water and molecular oxygen. The specific activity of catalase in sunberry was found to be 1.64 units·min^{-1}·mg^{-1} protein at the young stage, but it declined to 0.61 units·min^{-1}·mg^{-1} protein at the preripe stage. However, with the onset of ripening, the enzyme activity increases to higher levels measuring 2.1 units·min^{-1}·mg^{-1} protein (*figure 2*). The specific activity of catalase in the presently investigated sunberry fruit indicates that the changes in its activity at sequential growth stages are statistically significant ($p < 0.05$). Peroxidase, which is implicated in ethylene biosynthesis, membrane integrity and respiratory control, showed a decreasing pattern of its activity from the young stage to the ripe stage (*figure 2*). Selvaraj reported a similar trend of peroxidase activity in pineapple fruit [49]. The specific activity of peroxidase of sunberry was found to decline by 50% during its sequential growth stages, measuring 0.20 units·min^{-1}·mg^{-1} proteins at the young stage to 0.10 units·min^{-1}·mg^{-1} proteins proteins at the ripe stage, which is statistically significant ($p < 0.05$) (*figure 2*). The higher activity of peroxidase in the early stages of fruit growth is said to be due to the production of high amounts of oxidation product, but subsequently the production of oxidative product was less [50].

Softening is said to be one of the most dramatic changes that occur during the ripening of fleshy fruits [49]. Enzymes such as cellulase, polygalacturonase (PG) and pectin methyl esterase (PME) have been known to have active roles in the softening of cell walls. The specific activity of cellulase and PG exhibits non-significant changes, having very low activities (*figure 2*). The presently obtained values of the specific activity of cellulase are also in agreement with the findings of Tucker, who observed that the activities of cellulase may be less in the mature stage when compared with that of the ripening stage, as they are thought to be involved in the synthesis of new enzymes [30]. The results of our study support the

view of Trinchero *et al.*, who reported relatively low PG activity in goldenberry fruit [45]. Our results are also in agreement with those of Selvaraj, who reported higher values of PG activity in certain fruits from the young to the mature stage [49]. Besides, there are several reports which indicate loss in the activity of PG in unripe fruit and increased activity of PG during ripeness of the fruit [51]. The specific activity of PME of sunberry was also found to be relatively low, ranging from 0.001 $A_{620}{\cdot}min^{-1}{\cdot}mg^{-1}$ proteins at the young stage to 0.007 $A_{620}{\cdot}min^{-1}{\cdot}mg^{-1}$ proteins at the preripe stage (*figure 2*). A similar kind of observation was made by Trinchero *et al.*, who reported that the activity of pectinmethylesterase increases in goldenberry as its ripening proceeds [45]. Hence, our study indicates that the longer shelf life of the fruit of sunberry may be due to the much reduced activity of cell wall-softening enzymes.

4. Conclusion

To our knowledge, the work that we present here is the first report on physiochemical changes during growth and ripening of the fruit of *Physalis minima* var. *indica*. From the discussion based on the results obtained from our study, it may be concluded that the fruit of *P. minima* are nutritive and a rich source of starch at the young stage, while the ripe fruit is a rich source of sugars, free amino acids and proteins. Our work demonstrates that the chemical compounds associated with nutritional benefits to humans (*e.g.*, total phenols and ascorbic acid) reach their maximum value during the preripe and mature stages, respectively. The sunberry fruit is found to possess high specific activity of hydrolyzing and antioxidant enzymes, while the activity of cell wall-degrading enzymes is relatively low, indicating a better postharvest storage life. Hence the sunberry, which is an underutilized fruit, may be considered for commercial exploitation.

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Cambios físico-químicos del fruto de *Physalis minima* L. durante su crecimiento y su maduración.

Resumen — **Introducción**. La especie *Physalis minima* está muy extendida; se trata de una planta frutal herbácea anual, de la familia de las solanáceas, de crecimiento rápido y altos rendimientos. Sin embargo como ocurre con muchas otras plantas frutales insuficientemente utilizadas, la especie *P. minima* se investiga poco y las calidades nutricionales de su fruta apenas se conocen. Dado a que el physalis comestible es supuestamente rico en vitamina C, investigamos las modificaciones físico-químicas que intervienen en el curso del crecimiento y de la maduración de su fruto. **Material y métodos**. Los cambios de características físico-químicas, tales como el pH, los sólidos solubles totales, la acidez valorable, las clorofilas, los carotenoides, los carbohidratos (azúcares reductores, no reductores, azúcares totales y almidón), los aminoácidos libres, las proteínas totales, los fenoles totales, el ácido ascórbico, el etileno y la respiración, la actividad de las encimas hidrolíticas (amilasa e invertasa), encimas antioxidantes (catalasa y peroxidasa) y encimas de degradación de las paredes celulares (celulasa, poligalacturonasa y pectinmetilesterasa) fueron analizados en el fruto de *P. minima* en cinco fases de desarrollo sucesivo: joven, prematuro, maduro, antes de madurez, en estado de madurez. **Resultados y discusión**. Se observó un aumento progresivo del pH y de los sólidos solubles totales a lo largo del crecimiento y de la maduración del fruto, mientras que su acidez valorable aumentaba hasta la fase antes de madurez, tras la cual disminuía. Las clorofilas tuvieron tendencia a disminuir al mismo tiempo que aumentaba la cantidad de carotenoides. La cantidad total de almidón disminuyó significativamente con la maduración del fruto; y, de modo concomitante, aumentó la cantidad de azúcares reductores, no reductores y de azúcares totales. Asimismo, en el transcurso del crecimiento y de la maduración del fruto de physalis, tuvo lugar un aumento de la cantidad de aminoácidos libres, de proteínas, de fenoles. Por otro lado, la cantidad de ácido ascórbico aumentó igualmente en la fase del fruto en estado de madurez. Además, el physalis se comporta como un fruto climatérico debido al aumento de su producción de etileno y de su tasa respiratoria. La actividad específica de la amilasa aumentó a lo largo del periodo de crecimiento del fruto, pero la de la invertasa disminuyó tras la madurez. Las catalasas y peroxidasas mostraron una mayor actividad, lo que indicó una mejor aptitud para el atrape de los radicales libres; mientras que celulasa, poligalacturonasa y pectinmetilesterasa tuvieron tendencia a permanecer a niveles inferiores. **Conclusión**. El fruto de *P. minima* es nutritivo; es una fuente rica en azúcares, almidón, aminoácidos libres, proteínas, fenoles totales y ácido ascórbico. Este fruto es metabólicamente activo; presenta una actividad específica elevada de las enzimas hidrolizantes y antioxidantes, mientras que la actividad de las encimas de degradación de la pared celular es relativamente débil, lo que indica una aptitud mejor para la conservación después de la cosecha.

India / *Physalis minima* / fruto / crecimiento / maderamiento / etapas de desarrollo / propiedades fisicoquímicas