საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 15, №4, 2021
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 15, no. 4, 2021

Genetics and Selection

The Effect of Rice Blast on Nutritional Status of Rice

Maria Irakli*, Kalliopi Kadoglidou*, Ageliki Mygdalia*, Sopio Ghoghoberidze*, Fotis Kleisiaris*, Miranda Gorgiladze, Guram Papunidze§, Dimitrios Katsantonis***

**Institute of Plant Breeding and Genetic Resources, Hellenic Agricultural Organization - DEMETER, Thermi, Thessaloniki, Greece*
***Department of Agrotechnology and Agroengineering, Batumi Shota Rustaveli State University, Batumi, Georgia*
§The researcher of Department of Agricultural Raw Materials Production and Processing Technology of the Institute of Agrarian and Membrane Technologies of Batumi Shota Rustaveli State University, Batumi, Georgia

(Presented by Academy Member Guram Aleksidze)

Rice is the second major cereal crop in the world, while rice blast is its most destructive rice disease worldwide. Six varieties with different rice blast tolerance were inoculated with the fungus (Hight disease pressure, HDP), while another identical set was kept free of the disease (Low disease pressure, LDP). Grains derived by HDP and LDP plants were analyzed for protein content, as well as their phenolic profile and antioxidant activity. Results showed that protein content increased by 23.7%, the antioxidant activity and total phenolics increased by 10.0% and 7% in the HDP, respectively. Likewise, total flavonoids in most of the varieties were elevated ranging from 8.1 to 11.6%. Moreover, a significant trend of an antioxidant boost appeared in total phenolic acids of the grains and within the individual ones. Particularly, in the grains of the HDP total phenolic acids elevated by 6.9% more than in the LDP. Ferulic and p-coumaric acids, the most important acids of rice grains elevated to 4.2% and 13.7%, respectively. Syringic acid was increased by 20.8%, while the elevation was more pronounced in the most tolerant varieties. In the HDP plants, the overall elevation of the 4-hydroxy-benzoic acid ranged from 5.3% to 17.7% and the sinapic acid increased by 35%. Regarding the varieties, in general it was not possible to draw clear conclusions concerning the individual phenolic acids alterations. However, the most stable trend appeared in the highly tolerant variety, where in four out of six acids, it was included in genotypes with the highest phenolic acids elevation. *© 2021 Bull. Georg. Natl. Acad. Sci.*

Antioxidants, biochemical, defense, phenolic acids, *Pyricularia oryzae*, resistsance

Rice (*Oryza sativa* L.) is considered among the major staple crops, worldwide. Since rice is included in the diet of most populations around the world, it plays an important role in the concentration of several essential nutrients humans ingest daily.

Rice blast caused by *Pyricularia oryzae* (Cavara) is the most destructive disease of rice (*Oryza sativa* L.) worldwide causing yield loss at varying levels depending on several factors like stage of the crop, degree of cultivar susceptibility and environmental conditions. Besides yield losses, it is critical that rice blast fungus affects rice quality attributes [1]. Chemical control is the predominant way of managing rice blast, particularly by application of the most effective blasticide, tricyclazole [2].

Plant responses to stresses include activation of ion channels, production of reactive oxygen species scavenging enzymes, accumulation of hormones, and expression of stress tolerance genes. Pathogenesis-related (PR) proteins are a structurally diverse group of plant proteins that are toxic to invading fungal pathogens. They are widely distributed in plants in trace amounts but are produced in much greater concentrations following pathogen attack or stresses. Varying types of PR proteins have been isolated from each of several crops and from several plant organs, e.g., leaves, seeds, and roots including rice [3, 4]. The hypersensitive reaction to a pathogen leads to the induction of numerous plant genes encoding defence proteins [5].

Additionally, rice contains many non-nutrient bioactive compounds known as antioxidants, including phenolic compounds, tocopherols, tocotrienols and oryzanol. Phenolic compounds play an important role as defence molecules to protect plants from various adverse conditions or agents, especially fungus and other pathogens [6]. Researchers have demonstrated that phenolic compounds have antioxidant activities and free radical scavenging capabilities [7, 8].

Many studies reported that phenolic compounds were elevated in rice leaves infected by rice blast, particularly resulting from the brown pigment areas around the leaf lesions [9]. Contrariwise, Toan et al. [10] found that total phenolics were decreased in the leaves of infected rice cultivars susceptible and resistant to rice blast. Moreover, they reported that, in non-infection conditions, the total phenolic compounds in leaves of susceptible cultivars were higher than in the resistance ones. It has been more than 20 years since the first identified flavonoids isovitexin, α-tocopherol, and γ-oryzanol in rice as having antioxidant activities comparable to that of butylated hydroxyanisole, are a common food preservative [11]. In addition, rice produces a wide array of phytoalexins, inducible secondary metabolites, in response to pathogen attacks and environmental stresses. It is reported by various authors that the flavonoid phytoalexin sakuranetin was increased in leaves after the hypersensitive response of rice plants infected by the rice blast fungus [12]. On the contrary, Toan et al. [10] concluded that total flavonoids in rice leaves were reduced in some resistant and susceptible varieties. However, they reported no significant differences in other tested varieties, so that they could not correlate phenolics and flavonoids with the rice blast resistant levels. Nevertheless, these findings are in total contradiction with relative literature published in the last 30 years. Other studies have shown that several phenylamides (amine-conjugated phenolic compounds) play a role as defence-related agents exhibiting antimicrobial activity against rice pathogens [13]. Many researchers investigated the effects of rice blast on the phytoalexins content and the antioxidant capacity in leaves, studying the resistance responses of the rice system to the fungus invasion. Moreover, many attempts were conducted to correlate these results with host resistance and plant defence mechanisms [9, 10]. Concerning the correlations between rice blast and rice plant biochemistry, Suzuki [14] reported that normal activity responds rapidly with necrosis against mechanical injuries or foreign matter introduced from outside; it produces a certain lethal substance, such as phytoalexin, during this response. Rice plants assimilate ammonium into amino acids and proteins and produce phenolic compounds, and these are the most important factors for the maintenance of such activity. However, there are no other published studies, reporting the effects of rice blast on the production of phenolic compounds and antioxidant capacities of rice.

The aim of the present study is to investigate the effect of rice blast on the defence mechanisms in HDP and LDP disease treatments on PR protein, phenolic profile and antioxidant activity in rice.

Materials and Methods

Field experiments. Two sets of experiments were carried out at Experimental Station of the Institute of Plant Breeding and Genetic Resources, in Kalochori, Thessaloniki, Greece, in 2014 and 2015 (40°37'0.70"N, 22°49'50.48"E). The soil of the experimental area was silty loam (Aquic Xerofluvents) with a pH of 7.5 and 1.6% organic matter. Six rice varieties with varying levels of susceptibility to rice blast were selected: Ariete, Cigalon, LAB PG, Pegonil, Colina and Maratelli, as highly susceptible control [2]. All six varieties belonged to the European core collection maintained at the seed bank of the Institute obtained by two EU projects, RESGEN 1996-1999 and EURIGEN 2007-2010.

Seeds were sown in pots on the 9th of May 2014 and 6th of May 2015 and left to grow in nurseries. The field was flooded one day before transplanting, while the water was maintained between 5 and 10 cm deep until the grains reached the physiological maturity stage. The field was fertilised with 55 kg N ha^{-1} as ammonium sulfate (21% N), 33 kg P ha^{-1} as superphosphate, and 62 kg K ha^{-1} as potassium sulfate (42% K and 17% S), all applied by hand broadcasting before transplanting. A further 145 kg N ha^{-1} was applied when rice was at the tillering stage, 50 kg N ha^{-1} at the stem elongation, and finally 50 kg N ha^{-1} at booting. The experimental area was kept free of weeds by hand weeding. The seedlings were transplanted by hand into the field at the 5th to 6th leaf stage and arranged in a randomized complete block design with 3 replications for each treatment. Plots were 2 m long and consisted of 4 rows, 0.25 m apart each with 0.10 m on row spacing. When plants reached the 6th to 7th leaf stage were inoculated with rice blast conidia following the protocol described by Koutroubas *et al*. [1]. The plants were grown under two blast disease levels, high disease pressure (HDP) and low disease pressure (LDP) succeeded by spraying the appropriate treatments with the blasticide, tricyclazole, two applications of 300 gr ha^{-1} of active substance each: the first one on the 15th of July 2014 and 19th of July 2015 and the second 30 days after the first fungicide application. The use of the blasticide was necessary to facilitate the completion of the experiment for achieving the LDP treatment.

Meteorological conditions were recorded during the whole cultivation period for both years 2014 and 2015, using in-field installations of data loggers for air temperature and relative humidity (Hobo U23 Pro), as well as for solar radiation (Hobo Pyranometer) and for rainfall (Decagon High Resolution Rain Gauge) with in-field proximity installations.

Rice blast assessment. Blast assessments were performed on an individual plant basis. Leaf blast was recorded at 60 days after inoculation (DAI), using the lesion type rating scale from 1 to 5. This lesion type scale is a modification of the 1-6 scale [15] and it was expressed as a percentage of the infected panicles against the total number of them.

Protein determination. Protein content in brown rice samples was determined by the Kjeldahl method.

Phenolic extraction procedure. Free and bound phenolics of rice samples were extracted according to the method described by Irakli *et al.* [16].

Determination of total phenolics and total flavonoids. Total phenolics of both extracts were determined by Folin–Ciocalteu method according to Singleton *et al.* [17], and total flavonoids were determined using the aluminum chloride colorimetric method of Bao *et al.* [18].

Identification and quantification of phenolics were determined by high performance liquid chromatography according to Irakli *et al*. [19].

ABTS radical scavenging activity. Radical scavenging activity of rice extracts against ABTS radical cation was evaluated according to the protocol of Re *et al.* [20].

Statistical analysis. All statistical analysis was carried out over a year using both IBM SPPS Statistics v23 software package and MSTA-C. The obtained results were evaluated by analysis of variance, and the means were compared by Least Significant Differences test (LSD) at a 5% error probability ($p<0.5$).

Results

Meteorological data. The meteorological conditions (data not presented) in both years were similar. Minimum and average air temperatures throughout both cultivation periods were almost identical (19.6/19.5°C and 23.4/23.9°C), while the maximum temperature was 1.4°C higher in 2015. Average relative humidity was 5.9% higher in 2015 than in 2014, while total rainfall and solar radiation were almost identical in both years. In general, the weather condition in both cultivation periods was similar, while any existing difference could not affect or alter the development of rice blast fungus.

Rice blast assessments. Leaf blast appeared in all varieties grown under High Disease Pressure (HDP) after the inoculation with the fungus in 2014 and 2015. The average leaf blast severity (1-5 lesion type scale) was 1.18 in the LDP plants and 3.23 in the HDP plants, showing an increase of 62.4% due to the inoculation (Table). Moreover, the infections appeared in the HDP revealed a successful infection, while the marginal leaf blast severity on the non-inoculated LDP plants was due to the blasticide spraying. Within the HDP treatment the highest leaf blast severity among the tested varieties appeared in LAB PG (4.38), followed by Pegonil (3.92) and Maratelli (3.58) showing significant differences between them. The rest of the varieties (Colina, Ariete and Cigallon) occurred as tolerant to leaf blast. Neck blast incidence, appeared only in the inoculated plants, was increased at a level of 11.9% compared to LDP plants (Table). The highest neck blast incidence in the HDP treatment appeared in Maratelli (16.9%) followed by LAB PG (12.9%) and Pegonil (11.6%), with significant differences between them. Regression analysis of both leaf and neck blast over years revealed a positive correlation between both

Table. Leaf blast (Scale 1-5), Neck blast (%), Yield per plant and Yield Reduction (%) in the six varieties tested in 2014 and 2015 under two disease levels, LDP (Low Disease Pressure) and HDP (High Disease Pressure)

	Leaf blast (1-5)		Neck blast (%)		Yield/plant (g)		Yield Reduction (%)
Variety	**LDP**	**HDP**	**LDP**	**HDP**	**LDP**	**HDP**	
Ariete	1.00 g*	2.50 de	0.0 f	8.8 e	13.8 d	9.7 e	29.5
Cigalon	1.08 g	2.33 e	0.0 f	11.5 c	13.2 d	10.5 e	20.6
LAB PG	1.25 g	4.38 a	0.0 f	12.9 b	20.3 a	16.1 bc	20.5
Pegonil	1.58 f	3.92 b	0.0 f	11.6 c	13.5 d	10.7 e	20.7
Maratelli	1.17 g	3.58 c	0.0 f	16.9 a	18.1 ab	14.6 cd	19.5
Colina	1.00 g	2.68 d	0.0 f	9.9 d	16.8 b	13.3 d	20.8
Average	**1.18**	**3.23**	**0.0**	**11.9**	**15.9**	**12.5**	**21.9**
LSD	**0.29**		**0.94**		**2.25**		

[*] Values followed by the same letter in both LDP and HDP columns are not significantly different according to LSD test at $p \leq 0.05$

types of disease symptoms with an R^2 value of 0.633 [(Leaf blast $_{1-5}$) = 1.33 + 0.147 x (Neck Blast %)] (data not shown). The differences in the blast infection levels observed among the tested varieties were most likely due to the genetic differences, since similar cultural practices and conditions were adopted during the experimentation.

Protein content. Protein content of the grains was greatly affected by rice blast resulting in an overall increase of 23.7% (Fig. a). The most pronounced increase appeared in the susceptible control variety Maratelli (38.3%) followed by Ariete (31.8%) and Cigalon (25.7%), while the lowest increase appeared in Pegonil (8.6%).

Total phenolics, total flavonoids and antioxidant activity. Rice blast affected the antioxidant compounds of the rice grains. Results showed that total phenolics were 10% higher in the LDP treatment in most of the varieties tested (Fig. b). The highest increases appeared in Cigalon (tolerant one) and LAB PG (the most susceptible one), meaning that total phenolics are affected independently of the variety susceptibility level. Moreover, Maratelli and Ariete appeared with no significant differences in the total phenolics between the two disease treatments.

On the contrary, no significant differences were observed in the total flavonoid content of HDP and LDP rice grains in the most of varieties tested (Fig. c). It is noteworthy that only in Maratelli the total flavonoid content was significantly higher in the HDP treatment compared to the LDP one.

Additionally, the antioxidant capacity of rice grains as measured by ABTS radical scavenging

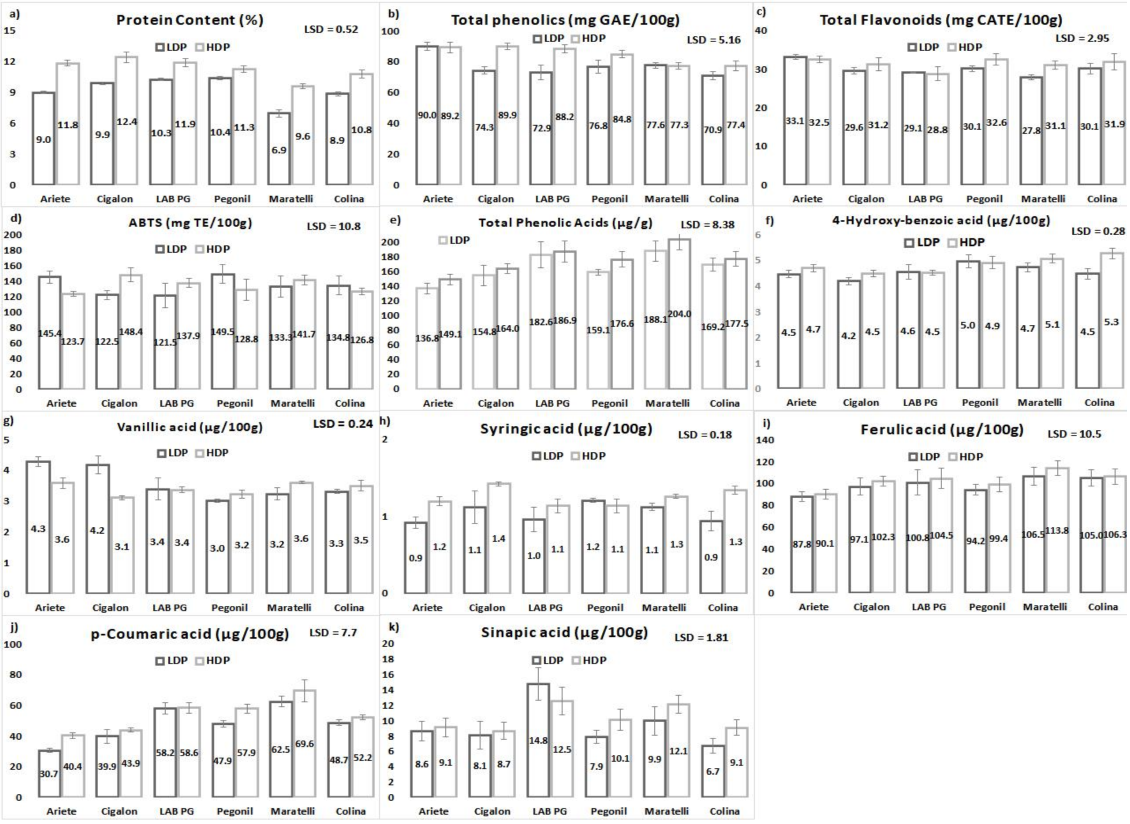

Fig. Differences between the HDP and LDP treatments in: a) Protein content, b)Total Phenolics, c) Total Flavanoids and d) ABTS, e) Total Phenolic Acids, f) 4-hydroxy-benzoic acid, g)Vannilic Acid, h) Syringic Acid, i) Ferulic Acid, j) P-Coumaric acid, k) Sinapic Acid.

activity was increased significantly at the level of 7% in the HDP treatment. ABTS values showed great variation among the varieties (Fig. d). Particularly, in the susceptible variety Pegonil and in Ariete and Colina (the tolerant ones), ABTS values were significantly increased in the HDP treatment at levels of 10.8%, 10.6 and 8.5%, respectively. Moreover, in LAB-PG (the most susceptible variety), and Cigalon (the most tolerant one) ABTS values were elevated 4.7% and 3.1%, respectively.

The total identified phenolic acids profile included ferulic, p-coumaric, sinapic, 4-hydroxy-benzoic, vanillic and syringic acid. In general, the overall trend was that rice extracts of HDP grains obtained 6.9% higher levels of total phenolic acids (sum of identified phenolic acids in free and bound extracts) than in the LDP (Fig. e). Pegonil had 11.0% more total phenolic acids, followed by Ariete (9.0%) and Maratelli (8.5%), with significant differences between the two treatments. Although, the increases in total phenolic acids between LDP and HDP treatments in Cigalon, LAB PG and Colina were not significant.

Considering the fact that ferulic acid contributed 59.8% of the total phenolic acids, it is evident that this acid along with p-coumaric plays the most important role in the elevation of the antioxidant activity triggered by the rice blast infection. Ferulic acid, was significantly increased by 4.2% overall in the HDP treatment compared to the LDP one. However, among the varieties no significant elevations were observed (Fig. i). The greatest increases appeared in Maratelli (6.8%), Pegonil (5.5%), and Cigalon (5.3%). Lower increases appeared in the tolerant varieties Ariete (2.5%) and Colina (1.2%). Thus, taking into account the overall significant increase of ferulic acid, a clear trend is evident. Results from p-coumaric acid determination revealed an overall increase of 13.7% in the grains of the HDP rice plants compared to the LDP ones (Fig. g). The most pronounced increase appeared in Ariete (31.9%) followed by Pegonil (20.9%) and Maratelli (11.3%) (Fig. j). Moreover, no significant elevations were observed in Cigalon (10.2%), Colina (7.1%) and LAB-PG (0.7%). Therefore, the effect of rice blast induced elevation of p-coumaric acid is clear, while this acid represents almost one- third (29.8%) of the total phenolic acids. Moreover, there was a 13.7% increase of sinapic acid in the HDP treatment compared to the LDP one. Specifically, the most pronounced increase was observed in the most tolerant variety Colina (35%), followed by Pegonil (28.7%), Maratelli (21.7%), with significant differences between the two treatments. Moreover, no significant increases appeared in Cigalon (7.0%) and Ariete (5.3%) (Fig. k). However, in the most susceptible variety, LAB PG, sinapic acid was 15.3% reduced. Total phenolic acids contain 5.7% of sinapic acid and it is the third most considerable acid.

Furthermore, results among the minor phenolic acids have shown alterations between the HPD and LPD treatments (Fig.). The 4-hydroxy-benzoic acid determination revealed that there was a 5.9% increase in the HDP compared to the LDP treatment (Fig. f). The most pronounced increase appeared in Colina (17.7%), followed by Maratelli (7.1%), Cigalon (7.0%) and Ariete (5.3%). However, the differences between the two disease treatments in Pegonil and LAB-PG were not significant. The 4-hydroxy-benzoic acid in the current study represents 2.7% of total phenolic acids in rice grains. However, contradictory results were obtained from vanillic acid determination, while all differences between the HDP and LDP treatments were significant. Overall, the vanillic acid concentration was 3% lower in HDP treatment than in LDP (Fig. g). Particularly, in the most tolerant varieties, Ariette and Cigalon, vanillic acid was 16.1% and 25.3% lower in the HDP than in the LDP treatment, while the reduction was marginal in LAB-PG (0.6%). On the contrary, vanillic acid was elevated in Maratelli (11.5%), Pegonil (6.9%) and

Colina (5.6%). Vanillic acid represents only the 2% of the total phenolic acids in the rice grains. Furthermore, syringic acid was determined 20.8% higher in HDP treatment than in LDP one (Fig. h). Particularly, it was higher in Colina (42.9%), Ariete (30.4%), Cigalon (27.1%) LAB PG (18%) and Maratelli (12.3%). Contrariwise, syringic acid was reduced in the grains of Pegonil in the HDP treatment. Syringic acid represents only 0.7% of the total phenolic acids in the rice grains.

Discussion

In both years of experimentation, meteorological conditions did not affect the disease development, since the most important parameters for rice blast pathogenesis, minimum (evening hours) and average temperatures, were almost identical [2].

Regarding the enhancement of protein content of grains, it is possible that this fungal induced protein increase is connected to PR proteins, due to their strong antifungal activity [3, 21]. It is well documented in the literature that various attempts have been carried out to improve the rice grain's content of protein, as well as essential amino acids such as lysine and threonine. Schaeffer & Sharpe [22] reported that higher lysine plants (14%) were regenerated from calli subjected to inhibitory levels of lysine plus threonine. Other strategies to increase grains' protein content and essential amino acids were by modifying biosynthetic and catabolic fluxes [23] and also, through the generation of transgenic plants by over-expressing genes encoding the proteins with higher ratios of essential amino acids [24]. Thus, the protein elevation presented in the current study, is possible to be resulted from the two different treatments: a) the blasticide tricyclazole application on the LDP plants and b) the rice blast infection of the HDP growing plants. Moreover, to our knowledge there are only two reports, where tricyclazole altered the protein levels of the sprayed plants. Sapna and Mahesh [25] reported that tricyclazole slightly inhibited the protein content in the grains of tricyclazole treated rice plants at an average rate of 0.2% in four out of eight rice varieties tested. Additionally, Avinash [26] reported small decreases of protein content in maize grains treated with tricyclazole concentrations of 0.1-0.3%, ranged among 0.1-0.24 mg/g, while in the control treatment was higher (0.43 mg/g). Thus, it appears from these studies that any possible tricyclazole in protein levels were very marginal to be established as a significant alteration factor. However, the results of the current study showed that the protein content was significantly elevated in the HDP at a level of 23.7%, much higher than tricyclazole effect. Thus, this elevation of the protein contents could be attributed to PR proteins stored in the grains assimilates originated by the plant biotic stress. Moreover, changes in protein levels are an aspect of critical alteration of the nutritive status of the rice final product. Martin and Fitzgerald [27] demonstrated that proteins affect the amount of water that rice absorbs early in cooking, and the availability of water in early cooking will determine the hydration of the protein and the concentration of the dispersed and viscous phases of the starch.

Regarding the antioxidant compounds, the most important result is the overall elevations of total phenolics and flavonoids in the HDP treatment in comparison to those of the LDP plants. Comparing the current results with the existing literature, Toan et al. [10], reported that among several (eleven) phenolic acids detected in rice plant leaves (including all the tested ones in the present study except the sinapic acid), only catechol, cinnamic acid and vanillin were promoted in rice leaves inoculated with rice blast, while they suggested that further investigation was needed. Concerning the genotypic differences, it was very difficult to draw any clear trend to correlate rice blast varietal susceptibility with total phenolics and flavonoids. In the case of the phenolics, the highest elevations appeared in the most tolerant and susceptible varieties and not in the resistant ones, while in flavonoids, the elevation appeared only in the susceptible variety Maratelli.

According to Goufo and Trindade [28], the phenolic acids in rice were composed of 12-28% hydroxyl-benzoic acids and 61-89% hydroxyl-cinnamic acids. However, 4-hydroxy-benzoic acid in the current study represents only 2.7% of total phenolic acids in rice grains.

Generally, regarding the nutritional value, Reed [29] stated that large increases in animal productivity can be achieved by relatively small increases in digestibility and intake. Thus, even small changes in the nutritive status could lead to big enough benefits for food. Furthermore, there are plenty of reports in the literature where rice blast fungal invasion triggers elevations of the antioxidant activity in the rice infected leaves [9,10]. However, to our knowledge no other studies investigated the effect of rice blast infection on the nutritional status of the rice grains. Numerous studies have shown that the essential phytochemicals in fruits, vegetables and cereal grains, including rice, are significantly associated with reduced risk of developing chronic diseases such as metabolic disorders, cancers, cardiovascular disease, Alzheimer's disease and type 2 diabetes [30].

Conclusion

Rice blast induced elevations in protein, total phenolic and total flavonoid contents as well as their phenolic profile and antioxidant activity. A significant trend of an antioxidant boost appeared in the grains of the rice blast diseased plants regarding the total phenolic acids along with the individual ones. More specifically, in the major phenolic acids, ferulic and p-coumaric, these kinds of elevations could have altered the assimilable antioxidant activity of the rice grains.

Regarding the varieties, it was difficult to draw any constant trend to correlate susceptibility to the levels of increases of the individual phenolic acids concerns. The most stable trend occurred in the most tolerant variety, where the highest elevations appeared in the four out of six acids determined.

RICE-GUARD: (In-field wireless sensor network to predict rice blast), Project ID: 606583, funded under: FP7-SME, by European Commission, funding scheme: BSG-SME-AG – Research for SME associations/groupings.

გენეტიკა და სელექცია

ბრინჯის პირიკულარიოზის გავლენა ბრინჯის კვებით სტატუსზე

მ. ირაკლი*, კ. კადოგლიდუ*, ა. მიგდალია*, ს. ღოღობერიძე*,
ფ. კლეისიარის*, მ. გორგილაძე**, გ. პაპუნიძე§, დ. კატსანტონის*

* *მცენარეთა სელექციისა და გენეტიკური რესურსების ინსტიტუტი, საბერძნეთის სოფლის მეურნეობის ორგანიზაცია - DEMETER, თერმი, სალონიკი, საბერძნეთი*
** *ბათუმის შოთა რუსთაველის სახელმწიფო უნივერსიტეტის აგროტექნოლოგიისა და აგროინჟინერიის დეპარტამენტი, ბათუმი, საქართველო*
§*ბათუმის შოთა რუსთაველის სახელმწიფო უნივერსიტეტის აგრარული და მემბრანული ტექნოლოგიების ინსტიტუტი, სასოფლო-სამეურნეო ნედლეულის წარმოებისა და გადამუშავების ტექნოლოგიების განყოფილება, ბათუმი, საქართველო*

(წარმოდგენილია აკადემიის წევრის გ. ალექსიძის მიერ)

ბრინჯი მსოფლიოში მეორე მთავარი მარცვლეული კულტურაა, ბრინჯის პირიკულარიოზი კი მისი ყველაზე გამანადგურებელი დაავადება. პირიკულარიოზის მიმართ განსხვავებული ტოლერანტობის მქონე ბრინჯის ექვსი სახეობა ინოკულირებული იყო სოკოთი (დაავადების მაღალი ზემოქმედება, HDP), ასევე ბრინჯის იგივე სახეობათა ნაკრები თავისუფალი იყო დაავადებისგან (დაავადების დაბალი ზემოქმედება, LDP). გაანალიზდა პროტეინის შემცველობა, აგრეთვე ფენოლური პროფილი და ანტიოქსიდანტური მოქმედება HDP და LDP მცენარეებისაგან მიღებულ მარცვლებში. შედეგებმა აჩვენა, რომ პროტეინის შემცველობა გაიზარდა 23,7%-ით, ანტიოქსიდანტური აქტივობა, მთლიანი ფენოლები და რადიკალური გამწმენდი აქტივობა – 10%-ით და 7%-ით იმ მცენარეებში, რომელთაც ჰქონდათ დაავადების მაღალი ზემოქმედება (HDP). ანალოგიურად, ფლავონოიდების საერთო რაოდენობა ბრინჯის უმეტეს ჯიშებში მომატებული იყო 8,1-დან 11,6%-მდე. უფრო მეტიც, ანტიოქსიდანტის მომატების მნიშვნელოვანი ტენდენცია გამოჩნდა ფენოლურ მჟავებში. კერძოდ, დაავადების მაღალი ზემოქმედების მქონე მარცვლებში (HDP) აღინიშნა მთლიანი ფენოლური მჟავების 6,9%-ით მომატება დაავადების დაბალი ზემოქმედების მარცვლებთან შედარებით (LDP). ბრინჯის მარცვლების ყველაზე მნიშვნელოვანი მჟავების: ფერულისა და p- კუმარინის რაოდენობამ მიაღწია 4,2% და 13,7%-ს. სირინგის მჟავა გაიზარდა 20,8%-ით, მაშინ როცა მომატების მაჩვენებელი ყველაზე მეტად შეინიშნებოდა ბრინჯის ტოლერანტულ ჯიშებში. 4-ჰიდროქსი-ბენზოინის მჟავის რაოდენობა 5,3%-დან 17,7% შეადგინა დაავადების მაღალი ზემოქმედების მქონე მცენარეებში, ხოლო სინაპინის მჟავა გაიზარდა 35%-ით. ზოგადად, ჯიშების მიხედვით, შეუძლებელი იყო მკაფიო დასკვნების გაკეთება ინდივიდუალური ფენოლური მჟავების ცვლილებებთან დაკავშირებით. ამასთან, ყველაზე სტაბილური ტენდენცია გამოჩნდა მეტად ტოლერანტულ ჯიშში, სადაც ექვსიდან ოთხი მჟავას ყველაზე მაღალი დონე დაფიქსირდა. შედეგად, ბრინჯის დაავადებამ გამოიწვია ცილების, ფენოლური პროფილისა და მთლიანი ფლავონოიდების შემცველობის, აგრეთვე მათი ანტიოქსიდანტური მოქმედების გაზრდა.

REFERENCES

1. Koutroubas S.D., Katsantonis D., Ntanos D.A., Lupotto E. (2009) Blast fungus inoculation reduces accumulation and remobilization of the pre-anthesis assimilates to rice grains. *Phytopathologia Mediterranea* 48: 240-252.
2. Katsantonis D., Kadoglidou K., Dramalis Ch. and Pau Puigdollers (2017) Rice blast forecasting models and their practical value: a review. *Phytopathologia Mediterranea* 56: 187-216.
3. Agrios G.N. (2005) Plant Pathology, fifth ed, 952 pp. Elsevier Academic Press, Inc.
4. Wu J., Kim S.G., Kang K.Y., Kim J.G., Park S.R., Gupta R., Kim S.T. (2016) Overexpression of a Pathogenesis-Related Protein 10 Enhances Biotic and Abiotic Stress Tolerance in Rice. *The Plant Pathology Journal*, **32**(6): 552–562. https://doi.org/10.5423/ppj.oa.06.2016.0141
5. Stintzi A., Heitz T., Prasad V., Wiedemann-Merdinoglu S., Kauffmann S., Geoffroy P., Fritig B. (1993) Plant 'pathogenesis-related proteins and their role in defense against pathogens. *Biochimie*, **75**(8): 687–706. https://doi.org/10.1016/0300-9084(93)90100-7
6. Patra B., Schluttenhofer C., Wu Y., Pattanaik S. & Yuan L. (2013) Transcriptional regulation of secondary metabolite biosynthesis in plants. *Biochimica et Biophysica Acta (BBA) - Gene Regulatory Mechanisms*, **1829**(11): 1236–1247. https://doi.org/10.1016/j.bbagrm.2013.09.00
7. Chinprahast N., Tungsomboon T. & Nagao, P. (2016) Antioxidant activities of Thai pigmented rice cultivars and application in sunflower oil. *International Journal of Food Science & Technology*, **51**(1), 46–53. https://doi.org/10.1111/ijfs.12952
8. Irakli M.N., Samanidou V.F., Katsantonis D.N., Biliaderis C.G. & Papadoyannis I.N. (2016) Phytochemical profiles and antioxidant capacity of pigmented and non-pigmented genotypes of rice (Oryza sativa L.). *Cereal Research Communications*, **44**(1):98-110. https://doi.org/10.1556/0806.43.2015.033
9. Cho M.H. & Lee S.W. (2015) Phenolic Phytoalexins in Rice: Biological Functions and Biosynthesis. *International Journal of Molecular Sciences*, **16**(12):29120–29133. https://doi.org/10.3390/ijms161226152
10. Toan N.P., Thu Ha P.T. & Xuan T.D. (2017) Effects of Rice Blast Fungus (Pyricularia grisea) on Phenolics, Flavonoids, Antioxidant Capacity in Rice (Oryza sativa L.). *International Letters of Natural Sciences*, 61: 1–7. https://doi.org/10.18052/www.scipress.com/ilns.61.1
11. Ramarathnam N., Osawa T., Namiki M. & Kawakishi S. (1989) Chemical studies on novel rice hull antioxidants. 2. Identification of isovitexin, a C-glycosyl flavonoid. *Journal of Agricultural and Food Chemistry*, **37**(2): 316–319. https://doi.org/10.1021/jf00086a009
12. Dillon V.M., Overton J., Grayer R.J. & Harborne J.B. (1997) Differences in phytoalexin response among rice cultivars of different resistance to blast. *Phytochemistry*, **44**(4):599–603. https://doi.org/10.1016/s0031-9422(96)00619-x
13. Park H., Yoo Y., Hahn T.R., Bhoo S., Lee S.W. & Cho M.H. (2014) Antimicrobial Activity of UV-Induced Phenylamides from Rice Leaves. *Molecules*, **19**(11):18139–18151. https://doi.org/10.3390/molecules191118139
14. Suzuki N. (1965) Nature of resistance to blast. In: The rice blast disease. In *Proceeding of a Symposium at IRRI* 1963 (pp. 277–302). Blatimore, Maryland: The John Hopkins Press.
15. Notteghem J.L. (1981) Cooperative experiment on horizontal resistance to rice blast. pp. 43-51. Presented at the Blast and upland rice: report and recommendations from the meeting for international collaboration in upland rice improvement., Los Baños, Filipinas: International Rice Research Institute.
16. Irakli M.N., Samanidou V.F., Biliaderis C.G. & Papadoyannis I.N. (2012) Development and validation of an HPLC-method for determination of free and bound phenolic acids in cereals after solid-phase extraction. *Food Chemistry*, **134**(3):1624–1632. https://doi.org/10.1016/j.foodchem.2012.03.046
17. Singleton V.L., Orthofer R. & Lamuela-Raventós R.M. (1999) Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. *Oxidants and Antioxidants Part A*, 152-178. https://doi.org/10.1016/s0076-6879(99)99017-1
18. Bao J., Cai Y., Sun M., Wang G. & Corke H. (2005) Anthocyanins, Flavonols, and Free Radical Scavenging Activity of Chinese Bayberry (Myrica rubra) Extracts and Their Color Properties and Stability. *Journal of Agricultural and Food Chemistry*, **53**(6):2327-2332. https://doi.org/10.1021/jf048312z
19. Irakli M., Kleisiaris F., Kadoglidou K., Katsantonis D. (2018) "Optimizing Extraction Conditions of Free and Bound Phenolic Compounds from Rice By-Products and Their Antioxidant Effects *Foods* 7, 6:93. https://doi.org/10.3390/foods7060093
20. Re R., Pellegrini N., Proteggente A., Pannala A., Yang M. & Rice-Evans C. (1999) Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine*, **26**(9-10):1231-1237. https://doi.org/10.1016/s0891-5849(98)00315-3
21. Xiao N., Wu Y., Pan C., Yu L., Chen Y., Liu G., Li A. (2016). Improving of Rice Blast Resistances in Japonica by Pyramiding Major R Genes. *Frontiers in Plant Science*, 7. https://doi.org/10.3389/fpls.2016.01918
22. Schaeffer G.W. & Sharpe F.T. (1987) Increased Lysine and Seed Storage Protein in Rice Plants Recovered from Calli Selected with Inhibitory Levels of Lysine plus Threonine and S-(2-Aminoethyl)cysteine. plant physiology, **84**(2):509-515. https://doi.org/10.1104/pp.84.2.509

23. Long X., Liu Q., Chan M., Wang Q. & Sun S.S. M. (2013) Metabolic engineering and profiling of rice with increased lysine. *Plant Biotechnology Journal*, **11**(4):490–501. https://doi.org/10.1111/pbi.12037
24. Wong H. W., Liu Q. & Sun S. S. M. (2015) Biofortification of rice with lysine using endogenous histones. *Plant Molecular Biology*, **87**(3), 235-248. https://doi.org/10.1007/s11103-014-0272-z
25. Sapna B. & Mahesh M. K. (2011) Effect of fungicide-indofils bean on eight cultivars of rice (Oryza sativa). *Journal of Ecotoxicology and Environmental Monitoring*, **21**(6):517-522.
26. Avinash V.S. (2012) Effect of Tricyclazole on the Growth and Metabolism of Zea mays. *Nature Environment and Pollution Technology*, **11**(2):5.
27. Martin M. & Fitzgerald M. A. 2002. Proteins in Rice Grains Influence Cooking Properties! *Journal of Cereal Science*, **36**(3):285-294. https://doi.org/10.1006/jcrs.2001.0465
28. Goufo, P. & Trindade H. (2014) Rice antioxidants: phenolic acids, flavonoids, anthocyanins, proanthocyanidins, tocopherols, tocotrienols, γ -oryzanol, and phytic acid. *Food Science & Nutrition*, **2**(2):75-104. https://doi.org/10.1002/fsn3.86
29. Reed J.D. (1994) *Crop-Livestock Interactions: Implications for Crop Improvement in Sustainable Agriculture*. (R. S. Zeigler, S. A. Leong, & P. S. Teng, Eds.). Wallingford, U.K.: CABI.
30. Griffiths K., Aggarwal B., Singh R., Buttar H., Wilson D. & De Meester F. (2016) Food Antioxidants and Their Anti-Inflammatory Properties: A Potential Role in Cardiovascular Diseases and Cancer Prevention. *Diseases*, **4**(4):28. https://doi.org/10.3390/diseases4030028

Received August, 2021