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Effect of dipping on fruit-drying kinetics in 'Čačanska Rodna' and 'Stanley' plum cultivars

Olga Mitrović[1], Branko Popović[1], Miodrag Kandić[1], Aleksandar Leposavić[1], Ivana Glišić[1], Nemanja Miletić[2]

[1]Fruit Research Institute, Kralja Petra I 9, 32000 Čačak, Republic of Serbia
[2]University of Kragujevac, Faculty of Agriculture in Čačak, Ljubićska 30, Republic of Serbia
E-mail: omitrovic@institut-cacak.org

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Abstract. The paper presents the results of the effect of dipping on fruit-drying kinetics in two cultivars that represent the most significant source of prunes in Serbia ('Čačanska Rodna' and 'Stanley'). Dipping was performed in laboratory conditions, by submerging fruits in boiling water. Testing was performed at two drying temperatures, 70 °C and 90 °C in the experimental fruit dryer used for testing the convective drying method, to the point of attaining 75% of total dry matter content in the prune. While dipping at 90 °C, drying time is reduced by an average of 5% compared to the control (undpipped fruits) whereas at the drying temperature of 70 °C, reduction of drying time is about 10% in both tested cultivars.

Key words: prune, drying temperature, dipping, drying curves, drying rate

Introduction

Drying is one of the most important processes in food industry, and one of the most studied in food engineering. The most common form of drying agricultural foods such as fruits and vegetables, is convective drying carried out under a stream of heated air. Optimization of this process leads to a reduction in production costs and an increase in product quality. In order to optimize conditions of food dehydration, testing of drying kinetics in experimental dryers has been performed. In this sense, experimental dryers include those in which all the parameters relevant to drying kinetics such as temperature, flow and drying air humidity are continuously controlled and regulated (Sabarez, 2012; Aversa et al., 2007; Kandić et al., 2017). Different periodic of mass measurement was determined to monitor the loss of fruit mass in the course of drying – Bozkir (2006) carried out mass measurements every 10 minutes, Pavón-Melendez et al. (2002) measured the mass in the first hour of drying every 15 min and every 30 min for the next two hours of drying and then, every 60 min until the end of drying. Goyal et al. (2007) measured the mass every 30 minutes throughout the drying period, while Sabarez et al. (1997) and Pavón-Melendez et al. (2002) every 60 min.

In all experimental dryers, testing of the drying process, i.e. drying kinetics is performed using either individual fruits (Ratti, 1994; Togrul & Pehlivan, 2003) or fruits arranged on one tray (Margaris & Ghiaus, 2007; Kaya et al., 2007), all of which represents a thin layer drying model (Tripathy & Kumar, 2009; Diamante et al., 2010). Akpinar (2006) explained the terminology of thin layer drying as a drying of one layer (fruit or vegetable) in the form of whole fruits (like plums), or cut into pieces or leaflets (e.g. apples, pumpkins or leafy vegetables) that are densely arranged on a tray.

Drying kinetics is pre-conditioned, on one hand, by the character of drying air, while on the other hand, it depends on the characteristics of the initial material (Barbanti et al., 1994; Mitrović et al., 2013) and the use of various pre-treatments, of which most commonly used is dipping (Zlatković, 2003). Dipping can be performed by submerging fruits into hot (Tarhan et al., 2006) or boiling water (Sacilik et al., 2006), base solutions (Pangavhane et al., 1999), fatty acid ester solutions (Di Matteo et al., 2002; Doymaz, 2004) of various concentrations and temperatures, or in the fatty acid ester solutions with the addition of different bases (Doymaz, 2006), in order to distort or remove the wax layer without damaging the skin.

The aim of this paper was to determine whether dipping affects drying kinetics, i.e., the reduction of drying time of the tested plum cultivars, dried at two drying temperatures, 70 °C and 90 °C.

Material and Methods

Fruits of the plum cultivars 'Čačanska Rodna' and 'Stanley', taken from the experimental orchard at 'Preljina' facility of the Fruit Research Institute, Čačak were used for the testing, where agro- and pomotechnical measures commonly used for this kind of fruit species are regularly applied. The fruits intended for drying of about the same mass and maturation that corresponds to the drying process were picked.

Drying of fruits was carried out in an experimental dryer for testing the processes of convective drying (Kandić et al., 2007). An air-streaming drying process is applied at two constant air temperatures, 70 °C and 90 °C. Fruits without pre-treatment (control) and dipped (plum fruits under laboratory conditions submerged into boiling water for 20 s) were dried. On a stainless tray, fresh plum fruits were placed in a single layer, of average weight about 37 *g* of the cultivar 'Čačanska Rodna' and 43 *g* for the 'Stanley'. On each tray, there are 3,500 *g* of fruits, with 6 trays placed in the drying chamber. Through the trays with plum fruits, vertically streamed-heated air of pre-defined characteristics was introduced (temperature, flow). The speed of the airflow at the intersection of drying chamber was 1 *m/s*. Direction of vertical streaming in the course of drying was changed alternately and periodically at intervals of 60 *min*, the weight of the fruit on trays was measured every 2 *h*. Dipped fruits and those representing control are dried simultaneously in the same experiment, on trays symmetrically placed in the drying chamber, thus achieving the same drying conditions. Drying of fruits was completed once 75% of total dry matter has been reached.

The initial dry matter of fresh plum fruits and final dry matter of prunes were determined by standard gravimetric method, by drying at 105 °C until the constant mass was reached.

Nomenclature:

– DM [*kg* DM/*kg*] – content of total dry matter;
– W [*kg* W/*kg*] – moisture content on a wet base;
– U [*kg* W/*kg* DM] – moisture content on a dry base.

Results and Discussion

Plum fruits of the tested cultivars were picked at the optimal maturity stage for drying treatment, making the content of soluble dry matter of 21.40% and 16.80% for 'Čačanska Rodna' and 'Stanley', respectively; whereas the content of total dry matter was 22.80% and 19.47%, respectively (Tab. 1). 'Stanley' is a plum cultivar whose fruits for processing are most commonly used with soluble dry matter of about 16-18% (Barbanti et al., 1994; Doymaz, 2004), while the fruits of 'Čačanska Rodna' have higher contents of soluble dry matter (18%; Janda & Gavrilović, 1984; Mitrović et al., 2007). Table 1 shows the total dry matter content of the fruit at the end of the drying process, where all values were approximately 75%. This indicates that the drying process was properly carried out and that it is completed with just the same dry matter value set at the beginning of drying process. These values of dry matter of approximately 75% make prune microbiologically stable food (Vereš, 1991), and on the other hand, such fruits of the prune are suitable for consumption (Niketić-Aleksić, 1982).

Tab. 1. Contents of dry matter in fruits at the start and at the end of drying
Sadržaj suve materije u plodovima na početku i na kraju procesa sušenja

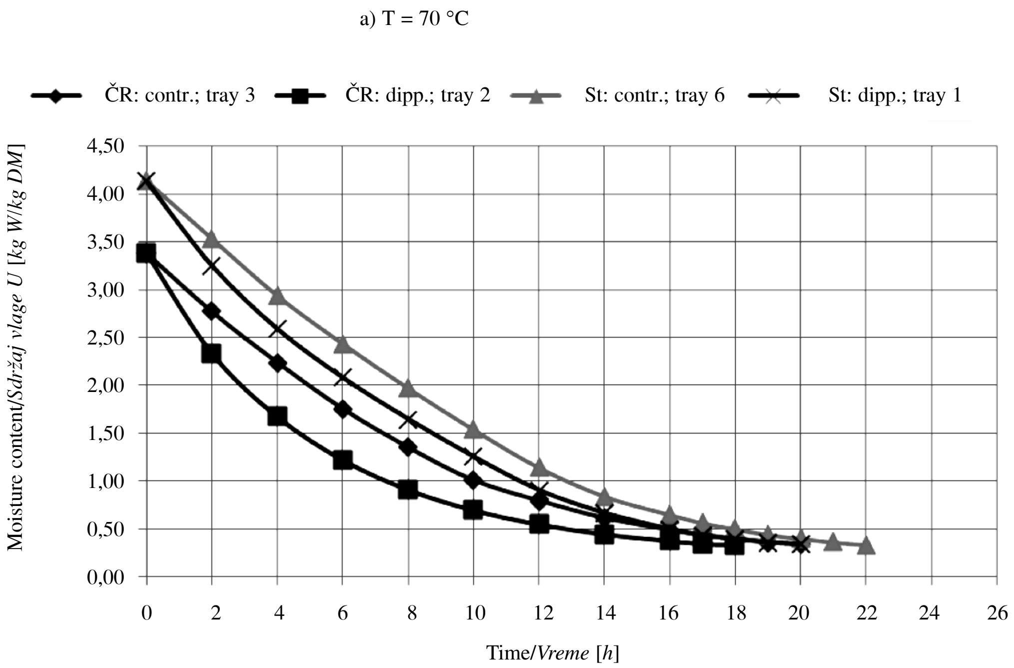
Cultivars *Sorte*	Soluble dry matter in fresh fruits *Rastvorljiva suva materija u svežem plodu* (%)	Total dry matter in fresh fruits *Ukupna suva materija u svežem plodu* (%)	Total dry matter in fruits at the end of drying *Ukupna suva materija plodova na kraju sušenja* (%)			
			Air temperature *Temperatura sušenja* 70 °C		Air temperature *Temperatura sušenja* 90 °C	
			Control *Kontrola*	Dipped *Dipovani*	Control *Kontrola*	Dipped *Dipovani*
'Čačanska Rodna'	21.40	22.80	74.88	75.15	75.24	75.09
'Stanley'	16.80	19.47	75.05	74.92	75.76	75.21

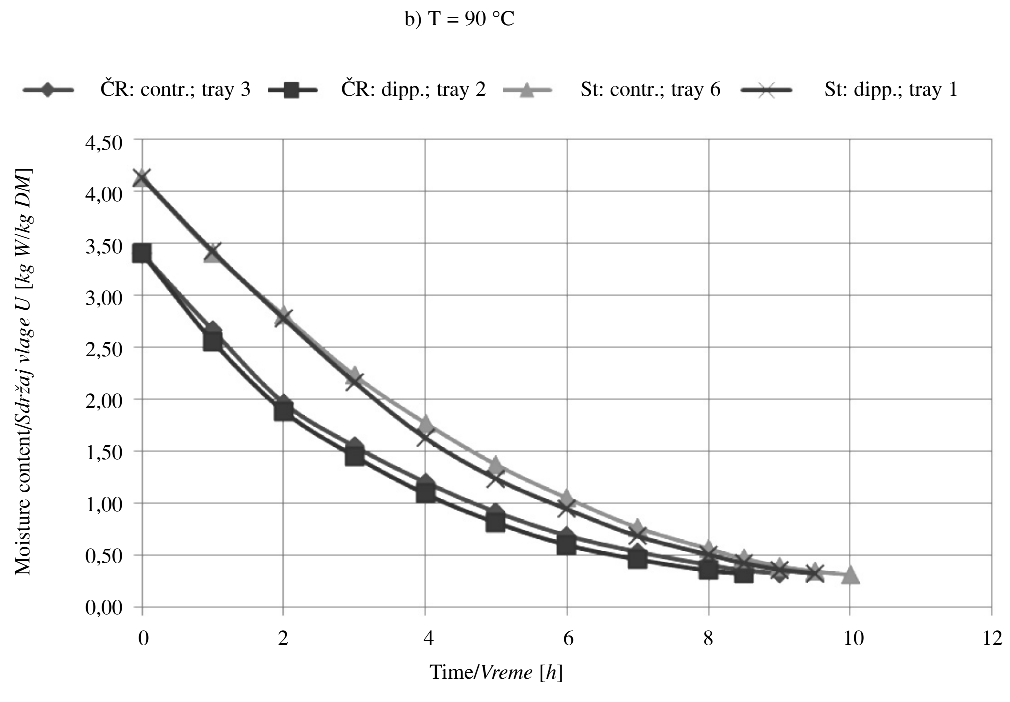
Drying kinetics can be presented by different curves that represent changes of basic material (plums) physical characteristics by time. Graph 1 shows the moisture content curves (on a dry base) of the plum fruits of the analyzed cultivars during drying at different drying temperatures, 70 °C and 90 °C. Drying kinetics is most often shown by this curve, because it annuls the difference in the initial data of the tested cultivars – the initial total mass and initial content of the dry matter of the fruits on a tray. Since the dry matter mass in fruits remains unchanged during drying, using the parameter moisture content on a dry base, it is possible to much better notice different drying kinetics of the analyzed plum cultivars depending on the technological preparation of fruits at different drying temperatures.

Analyzing the drying curves (Graph 1), the curves of the analyzed plum cultivars have been stated to start from different values, since the fruits of 'Čačanska Rodna' and 'Stanley' have different contents of total dry matter at the beginning of drying, i.e. the fruits have different moisture content on a dry base. The fruits of 'Čačanska Rodna' have a dry matter content of 3.38 *kg W/kg* DM, and the fruits of 'Stanley' 4.14 *kg W/kg* DM. Drying of fruits lasted up to 75% of the total dry matter, so the final moisture content on a dry base was about 0.33 *kg W/kg* DM. Analyzing Graph 1a, it has been stated that drying curves of dipped fruits and those representing control differ in both cultivars, in contrast to the drying curves at 90 °C (Graph 1b) where these differences are drastically lower. These differences are better observed in Graph 2 indicating drying curve rates. Since the drying rate is zero at the beginning of the process, drying rate curves from the coordinate start, i.e. from the zero value. Analyzing the drying rate curves of the dipped fruits and the fruits representing control, the highest drying rates were found to be achieved after the first measurement of the weight of the fruit on a tray, that was, after 2 *h* of drying.

High drying rate achieved at the beginning of the drying process allows the large amount of free water from plum fruits to evaporate at the beginning of the drying process. Table 2 shows the loss of free water in relation to the total evaporated water after 2, 4 and 6 *h* of drying for the dipped fruits and those representing control.

At 70 °C at the beginning of drying, when most important, drying rates of the dipped fruits were significantly higher than in the control sample, which is consistent with the results of Doymaz & Pala (2002), who dried grapes at 60 °C. After 2 *h* of drying, the loss of free water in relation to the total amount of evaporated water is in the case of dipped fruits of the 'Čačanska Rodna' (34.27%), compared to control (20.08%) , while for 'Stanley' the values were 23.25% and 15.84%, respectively. Although after the first mass measurement (2 *h*) drying of fruits enters the phase of decreasing drying rate (Datta, 2007), the evaporation of water from the fruits was still intense. After 6 *h* of drying, the dried fruits lost over 50% of the free water relative to the total amount of evaporated water in 'Stanley', while in 'Čačanska Rodna', such a large water loss was recorded after 4 *h* of drying. Dipping removes waxy layer from the fruit skin, because it represents the hydrophobic part of the skin that interferes with the undisturbed evaporation of water during drying (Goyal et al., 2007). The bloom and thickness of the skin are cultivar specificities, thus the fruits of the cultivar 'Čačanska Rodna' dried faster than

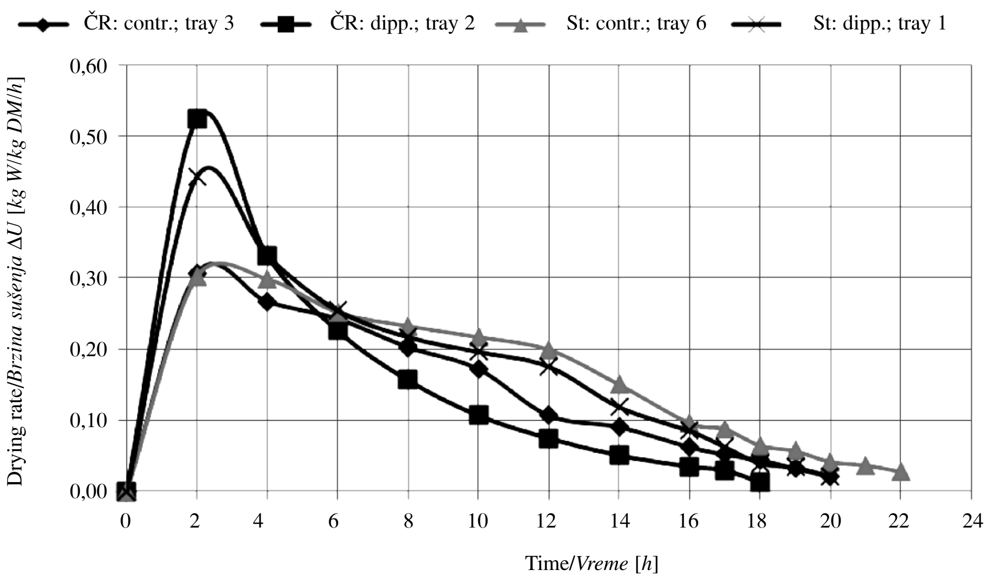




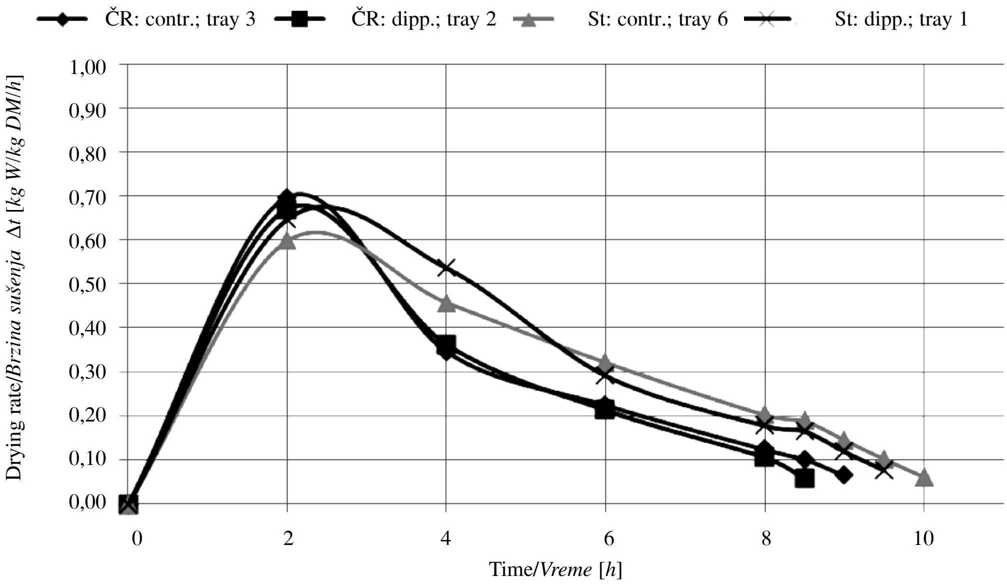
Graph 1. Contents of moisture on a dry base during the drying period at drying temperatures: a) 70 °C; b) 90 °C. ČR – 'Čačanska Rodna'; St – 'Stanley'

Graf. 1. Sadržaj vlage na suvu osnovu tokom sušenja na temperaturama sušenja: a) 70 °C; b) 90 °C. ČR – Čačanska rodna; St – Stanley

a) T = 70 °C



b) T = 90 °C



Graph 2. Drying rate of moisture on a dry base during the drying period at drying temperatures: a) 70 °C; b) 70 °C. ČR – 'Čačanska Rodna'; St – 'Stanley'

Graf. 2. Brzina sušenja vlage na suvu osnovu tokom sušenja na temperaturama sušenja: a) 70 °C; b) 90 °C. ČR – Čačanska rodna; St – Stanley

Tab. 2. The loss of free water in relation to the total evaporated water for the fruits of the tested plum cultivars in intervals of 2, 4 and 6 *h* in relation to the drying start, expressed in percentages
Gubitak slobodne vode u odnosu na ukupno isparenu vodu za plodove šljive ispitivanih sorata u intervalima od 2, 4 i 6 h u odnosu na početak sušenja, izražene u procentima

Cultivars *Sorte*	Intervals of time from the drying start *Intervali vremena od početka sušenja*	Loss of free water in relation to the total evaporated water *Gubitak slobodne vode u odnosu na ukupno isparenu vodu* (%) – Air temperature *Temperatura sušenja* 70 °C: Control *Kontrola*	70 °C: Dipped *Dipovani*	90 °C: Control *Kontrola*	90 °C: Dipped *Dipovani*
'Čačanska Rodna'	0 – 2 h	20.08	34.27	46.68	49.27
	0 – 4 h	37.56	55.99	71.51	75.10
	0 – 6 h	53.46	70.81	88.14	91.06
'Stanley'	0 – 2 h	15.84	23.25	34.67	35.62
	0 – 4 h	31.51	40.69	61.81	65.75
	0 – 6 h	44.73	54.09	80.72	83.74

the fruits of 'Stanley', which was in agreement with the results of Mitrović et al. (2018). The fruits that control the evaporation of water was much slower, which is why only the fruits of 'Čačanska Rodna' have lost over 50% of free water after 6 *h* of drying, while in the case of 'Stanley' the loss was 44.73. In our experiment, at drying temperature of 70 °C, in 'Čačanska Rodna', drying of dipped fruits lasted 18 *h* whereas in control sample 20 *h*; in the case of 'Stanley', drying lasted 20 and 22 *h*, respectively. This represents a shortening of the drying time of the dipped fruit compared to the control by 10% for 'Čačanska Rodna' and 9% for 'Stanley', which was in agreement with the results of Mitrović et al. (2018). Doymaz (2004) came to the similar conclusion that by dipping in the fatty acid ester of the 'Stanley' plum fruits at 65 °C, drying time was reduced by as much as 29.4% compared to undipped fruits. Also, Goyal et al. (2007) and Sacilik (2006) analyzed the kinetics of plum drying of dipped fruit in a sodium solution at 55 °C, 60 °C and 70 °C, Di Matteo et al. (2002) and Tarhan (2007) tested the effect of the application of different ways of plum dipping at 60 °C, though Tarhan (2007) also used the process of dipping in hot water. All the mentioned authors state that any dipping reduces the drying time of fruits, especially at temperatures below 70 °C.

Drying of plums at higher temperature (90 °C) was far more intense as the front of the water evaporation (moisture) from the fruit surface was rapidly transferred from the inner of the fruit (Datta, 2007), and therefore the drying of the dipped fruits and control sample was similar. The drying curves and drying rate curves of dipped fruits and control samples showed slightly different from each other, with the fruits of 'Čačanska Rodna' dried for a shorter time than the fruit of 'Stanley'. In the case of dipped fruits of 'Čačanska Rodna', almost 50% of free water evaporated after 2 *h* of drying, while for the fruits representing control slightly less than 50% of free water (46.68%) evaporated for the same time. The rate of drying fruits of 'Stanley' is somewhat lower, so that about 35% of free water evaporated after 2 *h* of drying. Therefore, the drying time of dipped fruits and those representing control for 'Čačanska Rodna' cultivar, was 8.5 *h* and 9 *h*, while for the fruits of 'Stanley', drying time was 9.5 and 10 *h*, respectively.

Conclusion

Based on these results, it can be concluded that dipping affects the reduction of drying time at 70 °C by 10% for 'Čačanska Rodna' cultivar and 9% for 'Stanley' in relation to the control. At 90 °C, the reduction of drying time was 5.5% for 'Čačanska Rodna' and 5% for 'Stanley'. Dipping as the most commonly used drying pre-treatment is recommended when drying plums at 70 °C.

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UTICAJ DIPOVANJA NA KINETIKU SUŠENJA PLODOVA SORTI ČAČANSKA RODNA I STANLEY

Olga Mitrović[1], Branko Popović[1], Miodrag Kandić[1], Aleksandar Leposavić[1], Ivana Glišić[1], Nemanja Miletić[2]

[1]*Institut za voćarstvo, Čačak, Kralja Petra I 9, 32000 Čačak, Republika Srbija*
[2]*Univerzitet u Kragujevcu, Agronomski fakultet u Čačku, Ljubićska 30, Republika Srbija*
E-mail: omitrovic@institut-cacak.org

Rezime

Sušenje šljiva je spor i dugotrajan proces zbog toga što pokožicu plodova pokriva voštani pepeljak, kao i zbog toga što se plodovi suše celi. Da bi se povećala brzina sušenja koriste se razni predtretmani, a najčešće korišćena operacija je dipovanje. U radu su prikazani rezultati uticaja dipovanja na kinetiku sušenja plodova dve najznačajnije sorte za sušenje u Srbiji (Čačanska rodna i Stanley).

Plodovi za sušenje su ubrani probirno, prosečne mase oko 37 *g* za sortu Čačanska rodna i 43 *g* za sortu Stanley, u fazi optimalne zrelosti za preradu sušenjem, tako da je sadržaj ukupnih suvih materija sorte Čačanska Rodna bio 22,80%, a sorte Stanley 19,47%. Sušenje plodova je obavljeno u eksperimentalnoj sušari za ispitivanje procesa konvektivnog sušenja. Primenjen je prostrujni postupak sušenja na dve konstantne temperature vazduha, 70 °C i 90 °C. Sušeni su plodovi bez prethodne pripreme (kontrola) i dipovani plodovi (plodovi šljive su u laboratorijskim uslovima potapani u ključalu vodu u trajanju od 20 *s*). Kroz lese sa plodovima šljive uvodi se vertikalno prostrujno zagrejan vazduh definisanih karakteristika (temperatura, protok). Brzina strujanja vazduha u preseku komore za sušenje je 1 *m*/*s*. Smer vertikalnog prostrujavanja u toku sušenja menjan je naizmenično i periodično u intervalima od 60 *min*. Sušenje plodova je završeno kada je u plodovima dostignuto 75% ukupne suve materije.

Kinetika sušenja se može predstaviti različitim krivama koje predstavljaju promene po vremenu različitih veličina stanja osnovnog materijala koji se suši. U radu su prikazane krive sadržaja vlage na suvu osnovu i krive brzine sušenja. Uočeno je da se na početku sušenja, pri temperaturi 90 °C ostvaruje velika brzina sušenja koja se manifestuje velikim gubitkom slobodne vode, pa je već posle 2 *h* isparilo oko 50% slobodne vode kod sorte Čačanska rodna. Brzina sušenja plodova sorte Stanley bila je nešto manja, tako da je posle 2 *h* sušenja isparilo oko 35% slobodne vode. Na ovoj temperaturi sušenja brzina isparavanja vlage iz plodova bila je slična kako kod dipovanih plodova tako i kod plodova koji predstavljaju kontrolu. Zbog toga su vremena sušenja dipovanih plodova i plodova koji predstavljaju kontrolu za sortu Čačanska Rodna iznosila 8,5 *h* i 9 *h*, a za plodove sorte Stanley 9,5 *h* i 10 *h*, po redosledu. Drugim rečima, na temperaturi sušenja od 90 °C dipovanje je uslovilo skraćenje vremena sušenja za 5,5% kod sorte Čačanska rodna, odnosno 5% kod sorte Stanley. Na temperaturi sušenja od 70 °C isparavanje vode iz plodova bilo je daleko slabijeg intenziteta, zbog čega je kod sorte Čačanska Rodna sušenje dipovanih plodova trajalo 18 *h*, a kod plodova koji predstavljaju kontrolu 20 *h*; kod plodova sorte Stanley sušenje je trajalo 20 *h* i 22 *h*, po redosledu. U ovom slučaju, u odnosu na kontrolu, dipovanje je uslovilo skraćenje vremena sušenja plodova za 10% kod sorte Čačanska Rodna i za 9% kod sorte Stanley.

Ključne reči: sušena šljiva, temperatura sušenja, dipovanje, krive sušenja, brzina sušenja