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COMPARATIVE EFFECT OF ORGANIC FERTILIZERS ON GROWTH AND YIELD OF LONG CAYENNE PEPPER IN TWO AGRO-ECOLOGICAL ZONES OF NIGERIA

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Abstract: The objective of this study was to improve the growth and yield of long cayenne pepper using 10 organic fertilizers. Organic fertilizers including tithonia compost (TC), poultry manure from a battery cage (PMB), poultry manure from dip-litter (PMD), pacesetter organic fertilizer (POF), sunshine organic fertilizer (SOF), ayeye organic fertilizer (AOF), brewery waste (BW), cow dung (CD), oil palm bunch ash (OPBA), cocoa pod husk (CPH) were collected at some specific locations in Oyo, Osun and Ondo States of Nigeria. The experiment was a 2×11 factorial experiment fitted into a randomized complete block design consisting of 10 organic fertilizers and the control at two locations (Ibadan and Ogbomoso) in 2008. The dosage of 130 kg N ha^{-1} of each of organic fertilizer was applied one week before transplanting. Six-week-old pepper seedlings were transplanted into a plot of 3m×2m ($6m^2$) with one seedling per hill. Growth and yield data collected were subjected to analysis of variance (ANOVA) and the least significant difference (LSD) at $p<0.05$ was used to compare the means. The results of the experiment reveal that the overall macronutrient content of the ten evaluated organic fertilizer sources was presented in the following order: SOF>OPBA=CPH>AOF>TC>POF>PMB=CD>BW>PMD. All the organic fertilizers more significantly enhanced the growth and yield of pepper than the control. The best three organic fertilizers at both locations in terms of fruit length were TC=SOF=PM. Fruit size at Ogbomoso was relatively bigger than that of Ibadan. The total fruit yield was highest under TC, SOF, PM and PMD at both locations. In conclusion, variations existed in the nutrient composition of the organic fertilizer. Meanwhile, TC, PMB, PMD and SOF were significantly similar in their ability to improve pepper yield. Moreover, PMB, TC and SOF significantly enhanced the vegetative growth of pepper.

Key words: organic fertilizer, pepper, seedlings, yield and growth.

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Introduction

Pepper (*Capsicum frutescens*) is an important fruit vegetable crop commercially grown in the tropics. The crop originated in Central and South America and was first domesticated in Mexico, but later taken to Europe by the Spanish explorers and Portuguese traders. The genus *Capsicum* consists of 22 wild species and five domesticated species. Its production and consumption have steadily increased worldwide in the 20th century due to its roles as both vegetable and spice (Salter, 1985; Wien, 1997). The five domesticated capsicum species are *C. annuum, C. frutescens, C. Chinense., C. baccatum,* and *C. pubescens* (Bosland and Votava, 2000). Also, the species can be divided into several groups based on the number of fruits per plant, pungency, fruit color, fruit shape, intended use, flavor and plant size. Most cultivars of pepper commercially cultivated in the world belong to the C. *annum* L. species (Smith et al., 1987; Bosland, 1992).

Pepper is produced throughout Nigeria. It is an integral part of diet and a main constituent of soups and stews consumed by the people. Its fruits are consumed fresh, dried or processed (Alegbejo et al., 1999; Gruben and Tahir, 2004). The average daily consumption of pepper by a Nigerian adult is estimated at 15g, which is higher than those of tomatoes and most other vegetables (Grubben and Tahir, 2004). Pepper requires a high level of mineral nutrients in the growing medium for effective performance. The nutrients essential for pepper include nitrogen, phosphorus and potassium which have been put at 130 kg, 160 kg and 140 kg per hectare, respectively (Grubben and Tahir, 2004). These nutrients are inherently low in the tropical soils, especially in Nigeria, but they can be improved either through bush fallow, shifting cultivation, crop rotation or by the application of organic or inorganic fertilizers.

However, the use of mineral fertilizer is costly and also has negative environmental effects. In addition, inorganic fertilizers may not replace trace mineral elements in the soil which often becomes rapidly depleted by crops. However, the nutrients in organic fertilizers are by nature released much more slowly than mineral fertilizers, hence the use of organic fertilizers makes nutrients readily available to crops at all the growth stages. Organic fertilizers from composts and other sources can be quite variable from one batch to another (Moyin-Jesu, 2008). These forms of fertilizers have been reported to improve soil structure and its long-term productivity as well as plant biodiversity and provide essential nutrients to the plant, and enhance the quality of the plant and the fruit, especially of *Capsicum annum* (Enwall et al., 2005; Alabi, 2006).

Worldwide, there is an increasing interest to use organic manures as a trail to compensate the decrease in soil fertility. The need to reduce costs of fertilizing crops has revived the use of organic fertilizers (Delate and Camberdella, 2004; Farhad et al., 2009). Organic fertilizers of various sources such as compost, animal

wastes, city wastes, domestic wastes, industrial wastes, and the like, release their nutrients for a long period of time, so they are sustainable and last longer in the soil. They are also capable of supplying nutrients through the growth periods of pepper. Therefore, it is necessary to look for alternatives, locally sourced organic materials that are inexpensive, sustainable, and that release their nutrient contents slowly and are environmentally compatible to enhance the yield and nutritional qualities of pepper.

The objective of this study was therefore to screen 10 organic fertilizer sources for nutrient contents and their effects on the growth and fruit yield of long cayenne pepper.

Materials and Methods

This study was conducted at the National Horticultural Research Institute (NIHORT) Idi-Ishin, Ibadan (7° 33´ N and 3° 56´ E; 168 m above sea level) and the Ladoke Akintola University of Technology, Ogbomoso Teaching and Research Farm, Ogbomoso (8° 10´ N and 4° 10´ E; 275 m above sea level), in 2008. Physical and chemical characteristics of the locations are described in Table 1.

Table 1. Chemical and physical characteristics of the soils of the experimental fields in Ibadan and Ogbomoso.

	Ibadan	Ogbomoso
pH (H_20)	5.9	5.5
Organic carbon (g kg^{-1})	4.4	3.8
Total N (g kg^{-1})	0.3	0.3
Available P (mg kg^{-1})	7.9	4.2
Fe (mg kg^{-1})	10.6	11.8
Cu (mg kg^{-1})	2.6	2.0
Zn (mg kg^{-1})	2.8	2.2
Ex. K (cmol kg^{-1})	0.2	0.3
Ex. Na (cmol kg^{-1})	0.3	0.3
Ex. Ca (cmol kg^{-1})	2.8	3.2
Ex. Mg (cmol kg^{-1})	0.6	0.6
Ex. acidity (cmol kg^{-1})	0.3	0.4
ECEC (cmol kg^{-1})	4.7	5.0
Base saturation (g kg^{-1})	930	924
Sand (g kg^{-1})	878	864
Silt (g kg^{-1})	110	122
Clay (g kg^{-1})	12	14
Textural class	Sandy loam	

The accession of pepper (*Capsicum frutescence*) (NHV-1A) used in the study is a high yielding and early maturing type developed in NIHORT. It is adapted to different agro-ecologies in Nigeria and it is relatively tolerant to viral, bacterial,

fungal and nematode diseases. Nursery trays were filled with a sterilized sieved mixture of top soil, sand and cured poultry manure in a ratio of 2:1:1 and seeds of the pepper accession were sown in the trays and watered daily for the first 14 days, and once in two days thereafter until the time of transplanting at six weeks after sowing (WAS).

The experiment was a 2×11 factorial experiment fitted into a randomized complete block design consisting of 10 organic fertilizer sources and the control at two locations (Ibadan and Ogbomoso). The dosage of 130 kg N ha^{-1} of each of organic fertilizer was applied one week before transplanting. Six-week-old pepper seedlings were transplanted at a spacing of 50cm × 50cm into a plot of 3m × 2m ($6m^2$) with one seedling per hill corresponding to 40,000 plants ha^{-1}. The nutrient composition of the ten organic fertilizers collected at specified locations in Oyo, Osun and Ondo States is described in Table 2, while the description of the 10 organic fertilizers is as follows:

Table 2. Nutrient constituents of organic fertilizers.

	g kg-1						mgkg-1		
Organic fertilizer	N	P	K	Ca	Mg	Na	Fe	Zn	Cu
TC	16.1	10.4	29.3	21.5	6.0	8.6	6.7	129.0	29.5
PMB	15.3	37.6	10.6	20.9	2.9	6.1	14.6	180.5	38.5
PMD	14.1	22.9	20.9	9.5	4.1	-	10.5	120.5	36.5
POF	12.0	45.0	38.0	25.8	5.2	4.6	6.2	118.0	34.0
SOF	36.0	50.0	30.3	45.6	3.0	2.1	11.4	-	-
AOF	3.5	37.8	26.1	22.0	8.0	5.6	8.5	110.0	-
BW	7.8	76.0	7.9	1.3	3.1	5.7	7.8	140.0	22.5
CD	5.0	28.0	24.0	18.5	6.4	8.4	-	-	-
OPBA	7.6	110.2	15.3	24.1	9.1	4.8	12.4	110.0	16.8
CPH	7.8	95.1	11.1	21.7	8.4	5.4	8.6	134.2	42.4

Note: TC = Tithonia compost, PMB = Poultry manure from a battery cage, PMD = Poultry manure from dip-litter, POF = Pacesetter organic fertilizer, SOF = Sunshine organic fertilizer, AOF = Ayeye organic fertilizer, BW = Brewery waste, CD = Cow dung, OPBA = Oil palm bunch ash, CPH = Cocoa pod husk.

Tithonia compost (TC) was prepared in NIHORT with Tithonia as the major component mixed with poultry manure at the ratio of 3:1 (Tithonia: poultry manure) on a dry weight basis (Akanbi, 2002; Adediran et al., 2003).

Poultry manure from a battery cage (PMB) was poultry layers' droppings collected from a battery cage at the Institute of Agricultural Research and Training (IAR&T), Research Farm, Moor Plantation, Ibadan in Ido Local Government Area of Oyo State.

Poultry manure from dip-litter (PMD) was poultry manure droppings collected from the poultry unit of ZARTECH farms at Gbekuba Area, Apata, Ibadan in Ido Local Government Area of Oyo State.

Pacesetter organic fertilizer (POF) is a product of the Oyo State organic fertilizer plant located at the Bodija cow market, Ibadan, Ibadan North Local Government Area of Oyo State. Market wastes (remnants of vegetables and food stuffs) and animal dung were the major components of this organic material.

Sunshine organic fertilizer (SOF) was collected from the Ondo State organic fertilizer factory at Igbatoro Estate, Akure in Akure South Local Government Area of Ondo State. It was produced from the combination of industrial, city and market wastes.

Ayeye organic fertilizer (AOF) was obtained from the Ayeye fertilizer factory located at Ayeye area, Ibadan, Ibadan North East Local Government Area of Oyo state. The major raw material was urban wastes.

Brewery waste (BW) was collected from the Nigerian Breweries factory, Alakia, Ibadan, Ibadan North West Local Government Area of Oyo State.

Cow dung (CD) was collected from the Akinyele cow market situated at Akinyele Local Government Area, Oyo State.

Oil palm bunch ash (OPBA) was collected at Ajagba village in Iwo Local Government Area of Osun state.

Cocoa pod husk (CPH). Dried cocoa pods were collected from the Cocoa Research Institute of Nigeria (CRIN), Idi-Ayunre, Oluyole Local Government Area of Oyo state.

Data on plant height, number of branches, number of leaves and leaf area (Salau et al., 2008), fruit length, fruit diameter, plant dry weight and fruit yield were taken from five randomly selected plants per plot. Fruit yield was determined by harvesting and weighing fruits from the five randomly sampled plants twice a week for five weeks, then total fruit weight was determined and average weight per plant was calculated and multiplied by plant population per hectare to get fruit yield in tons per hectare. The data collected were subjected to analysis of variance (ANOVA) and the least significant difference (LSD) at $p<0.05$ was used to compare the means.

Results and Discussion

Organic fertilizers from different sources significantly affected pepper height. Plants grown with TC, SOF, PMD, PMB and CPH were significantly taller than plants grown with other organic fertilizers. All the organic fertilizers produced plants that were significantly better than the NOF (control). Pepper responded positively to the applied organic fertilizers at both locations in a similar way. Meanwhile, pepper was significantly taller at Ogbomoso than at Ibadan. Significant variation also existed in the number of branches produced by the pepper plant in response to the applied organic fertilizer within and across locations. Pepper produced more branches at Ogbomoso than at Ibadan. All the organic fertilizer

sources at both locations were significantly better than the control. The top five fertilizers at Ibadan in terms of the number of branches included PMB (14.43), TC (13.25), BW (12.00), CD (15.17) and SOF (13.90). In addition, a similar result was obtained at Ogbomoso with PMB (17.84), TC (16.69), BW (15.59), CD (15.17) and SOF (13.90), being the best five fertilizers. Significant differences existed in the response of pepper to organic fertilizers at locations in terms of the number of leaves, and all the organic fertilizers produced plants that were significantly better than the control. The top five sources at Ibadan were TC (226.28), BW (215.06), SOF (214.91), PMB (207.11) and CD (182.04), whereas at Ogbomoso the best five were TC (237.88), SOF (226.51), BW (226.49) and PMB (218.60). At both locations, the leaf area of pepper in response to organic fertilizer was similar. Plants treated with organic fertilizers had significantly higher leaf area than the control (Table 3).

Table 3. Effects of organic fertilizers on the vegetative growth of long cayenne pepper in Ibadan and Ogbomoso.

Organic fertilizer	Plant height (cm)		Number of branches		Number of leaves		Leaf area (cm^2)	
	Ibadan	Ogbomoso	Ibadan	Ogbomoso	Ibadan	Ogbomoso	Ibadan	Ogbomoso
TC	80.89	87.01	13.25	16.69	226.28	237.88	1587.44	1610.96
SOF	81.39	87.54	10.49	13.90	214.91	226.51	1645.13	1670.26
PMD	79.25	85.52	9.53	12.97	170.04	181.34	901.06	925.83
PMB	79.50	85.89	14.43	17.84	207.11	218.60	1815.00	1850.01
CPH	80.02	86.26	9.66	13.04	168.67	180.32	1321.11	1345.82
CD	72.55	78.70	11.58	15.17	182.04	193.64	1265.83	1290.81
POF	71.96	78.14	9.64	12.93	134.22	145.88	1361.11	1384.26
BW	70.74	76.80	12.00	15.59	215.06	226.49	1279.32	1310.90
AOF	67.40	73.61	9.44	12.97	174.11	185.22	1352.02	1377.90
OPBA	63.31	69.28	10.00	13.71	174.11	184.69	1223.30	1247.71
NOF	53.04	59.13	5.77	9.24	132.00	143.78	1169.28	1194.59
$L.S.D_{0.05}$	5.05	5.09	1.57	1.66	6.37	6.44	14.9	20.89

Note: TC = Tithonia compost, PMB = Poultry manure from a battery cage, PMD = Poultry manure from dip-litter, POF = Pacesetter organic fertilizer, SOF = Sunshine organic fertilizer, AOF = Ayeye organic fertilizer, BW = Brewery waste, CD = Cow dung, OPBA = Oil palm bunch ash, CPH = Cocoa pod husk, NOF = No organic fertilizer.

Organic fertilizer sources significantly influenced the fruit length of pepper at both locations. Plants treated with organic fertilizers produced significantly longer fruits than the control. This may be due to the fact that they act as a substrate for soil microorganisms, which leads to increased microbial activity, thereby increasing the rate of organic material decomposition and release of nutrients for plant uptake (Nasef et al., 2004; Palada et al., 2004; Khalid and Shafei, 2005). The

best three organic fertilizer sources at both locations in terms of fruit length were TC, SOF and PMB (Table 4). At both locations, fruits of plants treated with organic fertilizer were significantly bigger than the control. The best three organic fertilizer sources in terms of fruit size include SOF (3.53cm) = TC (3.07cm) > BW (3.77 cm) (Table 4).

Table 4. Effects of organic fertilizers on yield components of long cayenne pepper in Ibadan and Ogbmoso.

Organic fertilizer source	Fruit length (cm)		Fruit diameter (cm)		Plant dry matter (g/plant)	
	Ibadan	Ogbomoso	Ibadan	Ogbomoso	Ibadan	Ogbomoso
TC	13.07	16.55	3.07	4.29	1.58	2.17
SOF	12.26	15.71	3.53	4.69	2.15	2.76
PMD	8.29	11.74	2.09	3.31	1.20	1.87
PMB	12.24	15.45	2.31	3.50	1.58	2.22
CPH	8.11	11.50	2.53	3.66	2.18	2.73
CD	8.26	11.74	2.00	3.28	1.39	1.91
POF	8.06	11.42	1.80	3.13	1.22	1.83
BW	7.28	10.79	2.25	3.77	1.37	1.83
AOF	9.06	12.42	2.17	3.39	1.60	2.21
OPBA	7.11	10.59	2.33	3.67	1.20	1.75
NOF	6.22	9.73	2.50	3.72	1.28	1.80
$L.S.D_{0.05}$	1.74	1.77	0.56	0.57	0.24	0.26

Note: TC = Tithonia compost, PMB = Poultry manure from a battery cage, PMD = Poultry manure from dip-litter, POF = Pacesetter organic fertilizer, SOF = Sunshine organic fertilizer, AOF = Ayeye organic fertilizer, BW = Brewery waste, CD = Cow dung, OPBA = Oil palm bunch ash, CPH = Cocoa pod husk, NOF = No organic fertilizer.

The total fruit yield/ha was highest under TC, SOF, PMB and PMD at both locations (Figure 1). The composition of any organic fertilizer is a function of the source, location and the materials from which they are made. Variations existed in nutrient compositions of organic fertilizers used because they were made from various materials. TC, PMB, PMD and SOF were significantly similar in their ability to improve pepper fruit production basically due to their composition. Pepper planted performed differently in response to the applied organic manure because the nutrient content of different organic fertilizer types differed. The level of the content may vary in the same quantity of different fertilizer types. Adetiloye et al. (1985) and Titiloye et al. (1985) have also reported that organic fertilizers vary with materials from which they are composted. The PMD, though was significantly similar in enhancing pepper growth and yield, did not have as many N constituents as TC, PMB and SOF.

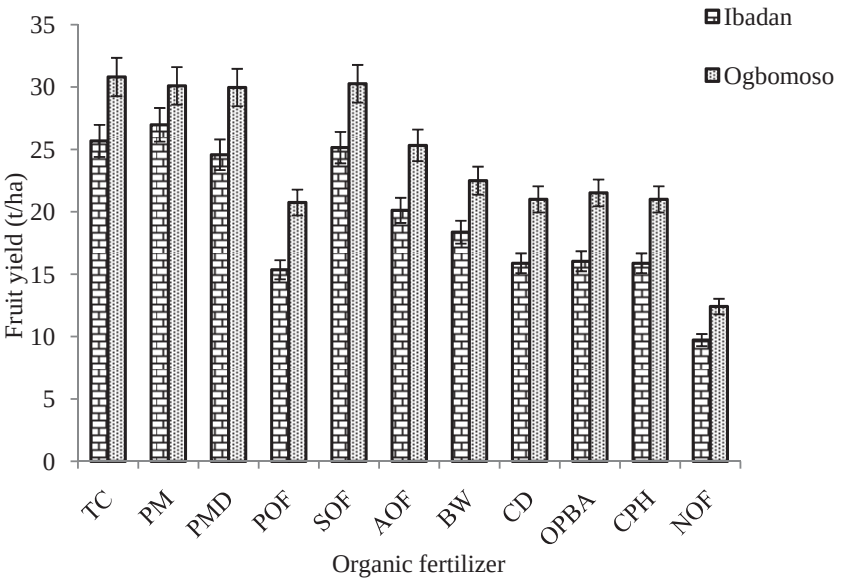

Figure 1. Effects of ten organic fertilizers on fruit yield of long cayenne pepper.

TC = Tithonia compost, PM = Poultry manure from a battery cage, DPM = Poultry manure from dip-litter, POF = Pacesetter organic fertilizer, SOF = Sunshine organic fertilizer, AOF = Ayeye organic fertilizer, BW = Brewery waste, CD = Cow dung, OPBA = Oil palm bunch ash, CPH = Cocoa pod husk, NOF = No organic fertilizer.

Conclusion

From this study, it could be concluded that different organic fertilizer sources were found to vary in macro and micro nutrients. TC, PMB, PMD and SOF were significantly similar in their ability to improve pepper yield, but TC, PMB and SOF could be selected based on their relatively higher N content.

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UTICAJ ORGANSKIH ĐUBRIVA NA RAST I PRINOS DUGAČKE KAJENSKE PAPRIKE U DVEMA AGROEKOLOŠKIM ZONAMA NIGERIJE

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R e z i m e

Cilj ovog istraživanja bio je da se poboljša rast i prinos dugačke kajenske paprike upotrebom deset organskih đubriva. Organska đubriva uključujući "titonijski kompost" (TC), živinski stajnjak iz kaveznog uzgoja (PMB), živinski stajnjak sa prostirkom (PMD), ostaci povrća i hrane + živinski stajnjak (POF), komercijalno organsko đubrivo nastalo kombinacijom industrijskog, gradskog i pijačnog organskog otpada, (SOF), komercijalno đubrivo od gradskog otpada (AOF), otpad iz pivara (BW), kravlju balegu (CD), pepeo od ostataka isceđenih plodova uljane palme (OPBA), ljusku od plodova kakaoa (CPH) sakupljena su na određenim lokalitetima u državama Ojo, Osun i Ondo u Nigeriji. Ogled je postavljen 2008. godine po potpuno slučajnom blok sistemu, kao dvofaktorijalni, gde je uključeno deset organskih đubriva i kontrola i koja su ispitivana na dva lokaliteta (2x11) Ibadan i Ogbomoso. Doza od 130 kg N ha-1 svakog organskog đubriva primenjena je jednu nedelju pre rasađivanja. Šestonedeljni rasad paprike rasađen je na parcelu dimenzije 3×2 m (6 m2) sa po jednom biljkom po kućici. Prikupljeni podaci o rastu i prinosu obrađeni su analizom varijanse (ANOVA), a najmanja značajna razlika (LSD) pri nivou $p<0,05$ korišćena je kako bi se uporedile srednje vrednosti. Rezultati ogleda pokazuju da je ukupan sadržaj osnovnih hranljivih elemenata deset ispitivanih organskih đubriva imao sledeći raspored: SOF > OPBA = CPH > AOF > TC> POF > PMB = CD > BW > PMD. Sva organska đubriva značajno su povećala rast i prinos paprike u odnosu na kontrolni tretman. Tri najbolja organska đubriva na dva lokaliteta u pogledu dužine ploda bila su TC = SOF = PM. Veličina ploda na lokalitetu Ogbomoso bila je relativno veća nego na lokalitetu u Ibadanu. Ukupan prinos ploda bio je najviši u tretmanima sa TC, SOF, PM i PMD na oba lokaliteta. Na kraju, varijacije su postojale u sastavu hranljivih elemenata organskog đubriva. U isto vreme đubriva TC, PMB, PMD i SOF su bila značajno slična po svojoj sposobnosti da poboljšaju prinos paprike. Pored toga đubriva PMB, TC i SOF značajno su uticala na vegetativni porast paprike.

Ključne reči: organsko đubrivo, paprika, rasad, prinos i rast.

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WEED INFESTATION AND PRODUCTIVITY OF MAIZE/SOYBEAN INTERCROP AS INFLUENCED BY CROPPING PATTERNS IN THE SOUTHERN GUINEA SAVANNA OF NIGERIA

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Abstract: Field experiments were conducted during the 2015 and 2016 cropping seasons at the Teaching and Research (T & R) Farm of the College of Agriculture, Kwara State University, Malete, to determine the effect of cropping patterns on weed infestation, growth and yield of a maize/soybean intercrop in the southern Guinea savanna of Nigeria. The experiments consisted of six treatments as follows: one row of maize alternated with one row of soybean (1:1), one row of maize alternated with two rows of soybean (1:2), two rows of maize alternated with one row of soybean (2:1), two rows of maize alternated with two rows of soybean (2:2), sole maize (1:0) and sole soybean (0:1). The treatments were laid out in a randomized complete block design with three replicates. Data collected were subjected to analysis of variance and means were separated by the least significant difference (LSD) at the 5% level of probability. Results showed that sole soybean consistently suppressed weeds and resulted in a higher yield. Similarly, the 2:1 ratio of maize to soybean did not only reduce weed density, it produced significantly higher yields of maize and lower yield of soybean, and had the higher land equivalent ratio and economic returns followed by sole maize.

Key words: Intercrop crop yield, economic returns, land equivalent ratio, Nigeria, weed density.

Introduction

Maize (*Zea mays* L.) is one of the most important staple food crops in west and central Africa. The savanna zone of west and central Africa has the greatest potential for its production due to a relatively higher incidence of solar radiation and a lower incidence of pests and diseases during the cropping season (Badu-Apraku et al., 2006). In Nigeria, maize is an important food,

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fodder and industrial crop grown both commercially and at the subsistence level (Iguisi, 2013). Maize production in Nigeria is becoming an increasingly important feature in both subsistence and large-scale agriculture. Due to poor yields, there has been a growing concern on raising its productivity and profitability. This general decline in yield has been attributed to high weed infestation. Yield losses of between 60 and 80% have been attributed to uncontrolled weed infestation in maize (Lagoke et al., 1998).

Worldwide production of maize is 785 million tonnes, with the largest producer, the United States, producing 42%. Africa produces 6.5%. Nigeria produced about 11.3 million tonnes in 2013, making it the largest producer in Africa (FAOSTAT, 2014).

Soybean [*Glycine max L.*] is one of the most important food legumes in Nigeria and other parts of the world. It is grown efficiently together with other crops in Nigeria, particularly cereals, such as maize, millet and sorghum (Adetiloye et al., 2005). More than 216 million tonnes of soybean were produced worldwide in 2007. Nigeria is the largest producer of soybean in sub-Sahara Africa (SSA), and it currently produces about 500,000 metric tonnes of this crop annually (Anonymous, 2016).

Soybean can be cultivated both as an oil crop and a pulse crop (Thakare et al., 2006). With an average protein content of 40%, it is protein-richer than any of the common vegetable or animal food sources found in Nigeria (Dugje et al., 2009). Soybean can improve soil fertility by contributing to soil nitrogen through nitrogen fixation (Kureh et al., 2005). It is also used for biodiesel production in Brazil (Ferrari, 2005; Barbosa, 2011).

Soybean has been shown to be sensitive to weed interference which is of great importance during the development of the crop. Weeds are strong competitors, not only for environmental resources, but they also release allelopathic substances, interfere in the process of harvesting and are hosts to many pests, insects, nematodes and pathogens that cause various diseases. In certain regions, weed induced soybean crop losses can reach 80% if not properly managed (Gazziero, 2004).

Intercropping is the growing of two or more crops simultaneously on the same piece of land in a manner that will permit the interaction of component crops in a spatial and temporal context (Steiner, 1984). The most common goal of intercropping is to produce a greater yield on a piece of land by making use of resources that would otherwise be utilized by a single crop (Jarenyama et al., 2000). It also provides greater stability in the supply of food and eliminates the risk of crop failure under adverse weather conditions or when there are disease and insect infestations (Sullivan, 2010). Intercropping is an efficient soil conservation practice due to the increased ground cover that it provides as well as the exploitation of different soil layers due to the different depths of the root

systems of the intercrop species (Jarenyama et al., 2000). Intercropping, through more effective use of water, nutrients and solar energy, can significantly enhance crop productivity compared with the growth of sole crops (Hussaini et al., 2001).

Guvene and Yildrim (1999) have reported that intercropping is a safer and more stable system of agricultural production than sole cropping for small farmers, where capital is limited and labor is not available. Many studies have indicated that intercropping with different legumes is more productive and profitable than sole cropping because of the complementary effect of an intercrop (Odion and Idem, 2005; Peter and Odion, 2008). Intercropping suppresses weed growth by providing an early ground cover due to a high plant population or a fast growing component crop, for example soybean. In many intercropping systems, only one weeding is required to produce optimum yield instead of two or three in the sole crop (Moody, 1975). However, the limitations of intercropping include difficulty in harvesting and in the efficient use of improved implements. Furthermore, a higher amount of fertilizer and irrigation water cannot be utilized properly as the component crops vary in their response to these resources and poor yield can occur due to the incompatibility between the component crops (Anonymous, 2015).

A maize-soybean intercrop is a popular cropping system adopted by farmers in Moro Local Government Area of Kwara State. However, there is a dearth of information on the right proportion of the component crops in the intercrop that will improve the productivity of maize and soybean and minimize weed infestation. This study therefore seeks to determine the best cropping pattern that will minimize weed infestation and raise the productivity of soybean and maize. The objectives of the project are to determine:

- the cropping pattern of a maize-soybean intercrop that will be more effective in weed control, and
- the cropping pattern of a maize-soybean intercrop that will raise maize and soybean productivity.

Materials and Methods

The experiment was conducted during the 2015 and 2016 cropping seasons at the Kwara State University Teaching and Research Farm, Malete, Kwara State (Lat. 08^{o} N, 71'; Long. 04^{o}E, 44'), located in the southern Guinea savanna of Nigeria. The experimental site is characterized by a bimodal rainfall pattern, which means that there are two rainfall peaks, in June and September, in the area where the experimental site was located. The soil was easily leached because of its sandy texture and low water holding capacity.

The experiment consisted of six treatments; namely, an intercrop of maize and soybean in the following pattern: one row of maize alternated with one row

of soybean (1:1), one row of maize alternated with two rows of soybean (1:2), two rows of maize alternated with one row of soybean (2:1), two rows of maize alternated with two rows of soybean (2:2). There were two control plots, a sole crop of soybean (0:1) and a sole crop of maize (1:0). These treatments were laid out in a randomized complete block design (RCBD) and replicated three times. The plot size was 4m x 4m with a 1-m alley between the replications and 0.5m between plots.

The land used for the experiment was mechanically plowed and harrowed, after which it was levelled and marked out into plots of 4m x 4m each. A space of 0.5m was left between plots, while 1m was left between replicates. Fertilizers were applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O to maize while 20 kg N, 20 kg P_2O_5 and 20 kg of K_2O were applied to soybean. These nutrients were provided by applying NPK 15:15:15 and urea fertilizers. The fertilizer was applied to maize in three split doses: the first dose (a starter dose) was applied before sowing, the second dose was applied three weeks after sowing (3 WAS) and the third, six weeks after sowing (6 WAS).

The sowing was done on the 11th and the 14th of July, 2015 and 2016 respectively. Both maize and soybean were sown at the same time. Three treated seeds of maize (var. SUWAN-1-SR) were placed in a hole, and the seedlings were thinned to one plant per stand, while four treated seeds of the soybean variety (TGX-1448-2E) were planted and the resultant seedlings were thinned to two plants per stand at 3 WAS. Both maize and soybean seeds were treated with Apron Star seed dressing material to protect the seeds against insect and disease attacks. Maize was spaced at 75cm x 25cm, while soybean was spaced at 75cm x 5 cm. The planting was done in a way that soybean rows alternated with that of maize. A hand hoe was used to control weeds.

The harvesting of maize was done first on the 30th of October, followed by soybean harvesting on the 14th of November, 2015, while maize was harvested on the 2nd of November and soybean on the 18th of November, 2016. The maize and soybean crops were harvested from a net plot of $9m^2$.The crops were left on the field to properly dry before further processing was done.

The following data were collected:

Weed dry matter (kg/ha)

Weed dry matter was determined by harvesting weeds within a $1m^2$ quadrat placed randomly in three locations within each plot. The weeds were put in well labelled paper bags and later oven-dried to a constant weight before the final weight was taken. The weed dry matter was determined at 6 WAS and at harvest.

Weed density (No./m^2)

Weed density was determined by counting the total number of weeds within each of the $1m^2$ quadrat placed randomly at three locations in each plot. The average of the total number of weeds was recorded as weed density per $1m^2$.

Plant height of maize and soybean (cm)

The plant height of maize and soybean was determined by randomly selecting five plants of each of the crop and measuring their height from the soil level to the apical bud. The plant height per plant was averaged to obtain the mean value per plot.

Leaf area (cm^2) of maize

The leaf area of maize was determined using the expression: Leaf area (LA) = Length (L) x breadth (b) x 0.75 (Moll and Kamprath, 1977).

Leaf area was obtained by measuring the length and breadth of the top, middle and bottom leaves of five randomly selected plants from each plot and the average of these measurements was multiplied by a factor of 0.75 to give leaf area per plant of maize.

100-seed weight of maize and soybean (g)

This was obtained by counting 100 grains of maize and soybean harvested from each plot, which were weighed on a bean balance to obtain 100-seed weight per plot.

Number of pods of soybean/plant

The pods of five plants of soybean selected at random per plot after harvest were counted manually. The average of the total number of pods per plant was calculated to obtain the mean number of pods/plant.

Grain yield of maize and soybean (kg/ha)

Grain yield was determined by weighing the grains harvested from each net plot of $9m^2$ which was converted to kilograms per hectares using the equation below:

$$\text{Grain yield/ha} = \frac{\text{Grain yield per net plot kg} \times 10{,}000m^2}{\text{Net plot size } (m^2)} \quad (1)$$

Land equivalent ratio (LER)

The productivities of the sole crop and the intercrops were compared by calculating the land equivalent ratio. This parameter is used to evaluate the yield advantage of intercropping. This parameter was calculated as follows:

$$LER = \frac{\text{Intercrop yield of crop A}}{\text{Sole crop yield of crop A}} + \frac{\text{Intercrop yield of crop B}}{\text{Sole crop yield of crop B}} \quad (2)$$

where: A is maize and B is soybean.

Economic analysis

Information on the cost of all the cultural practices from land preparation to harvesting and processing was collected from Kwara State Agricultural Development Programme (KWASADP), Ilorin, an agency responsible for extension services in Kwara State, Nigeria. The price of 1 kilogram of maize was obtained from the open market to calculate the income/total revenue. The economic analysis was carried out using partial budgeting (Okoruwa et al., 2005) to calculate the gross margin (profit) as follows:

$$GM = TR - VC \quad (3)$$
$$TR = (Ys \times Ps) \quad (4)$$
$$VC = M + L \quad (5)$$

where: GM = Gross margin/ha for each treatment,
TR = Total revenue, Naira/ha for each treatment,
VC = Variable cost, Naira/ha for each treatment,
Ys = Grain yield of crop (kg//ha) for each treatment,
Ps = Price of crop per kg,
M = Value of material input (seeds, fertilizers, insecticides, herbicides), and
L = Value of labour (land preparation, planting, insecticide and herbicide, fertilizer application, harvesting, processing and packaging). The cost:benefit ratio was calculated using the method of Joshua and Gworgwor (2001) as follows:

Cost benefit ratio = $\frac{TCP}{I}$, where TCP is the total cost of production and I is income/revenue.

Data analysis

The data collected was subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) package and where the F value was significant, the means were separated using the least significant difference test (LSD) at the 5% level of probability.

Results and Discussion

Rainfall

The total amount of rainfall recorded in 2015 was 1010.5mm, with the month of September having the highest rainfall, while January, February, April and August had low rainfall. In 2016, a higher rainfall of 1493.4mm was recorded, which was evenly distributed (Figure 1).

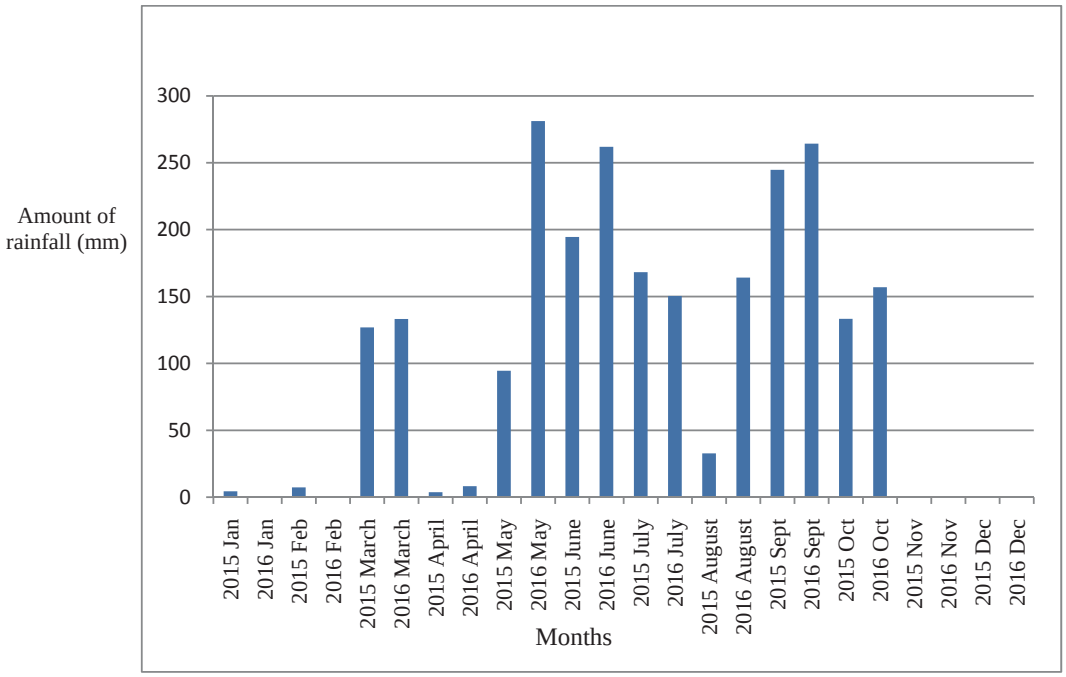

Figure 1. Monthly rainfall (mm) in the 2015 and 2016 seasons from the Teaching and Research Farm of the Faculty of Agriculture, University of Ilorin, Kwara State, Nigeria.

The effect of cropping patterns on weed infestation

Sole soybean (0:1) significantly reduced weed dry matter compared to the other treatments, except the 1:1 ratio of maize to soybean and the 1:0 ratio of maize to soybean cropping patterns, which supported comparable weed dry matter in both years and their means at 6 WAS. However, at 12 WAS, there was no significant difference between the treatments (Table 1). Cropping patterns had no significant

effect on weed density at 6 WAS (Table 2), however, at 12 WAS, the 0:1 ratio of maize to soybean cropping pattern had significantly low weed density which was comparable to other treatments except the 1:0 ratio of maize to soybean which had significantly higher weed density in 2016. This could have resulted from the higher rainfall recorded in the year which enhanced the growth of soybean to achieve early canopy closure that led to the suppression of weeds. This agrees with the findings of Akobundu (1980) who reported that crops like soybean, melon and sweet potato could provide early ground cover and shade out weeds when intercropped with other crops. Similarly, Dalley et al. (2004) have reported that quicker canopy closure and reduction in light penetration occur in narrow- compared with wider-row soybean, which subsequently causes reduction in weed seed germination and the growth of weeds later in the season.

Table 1. Effect of cropping patterns on weed dry matter.

Treatment	Weed dry matter (kg/ha)					
	6WAS[1]			12WAS		
	2015	2016	Mean	2015	2016	Mean
1:1	182.7[a2]	832.4[ab]	507.5[ab]	237.8[a]	199.9[a]	218.6[a]
1:2	230.0[a]	991.5[a]	610.8[ab]	272.0[a]	55.6[a]	163.8[a]
2:1	229.3[a]	1192.9[a]	711.1[a]	141.8[a]	155.6[a]	148.7[a]
2:2	245.3[a]	1095.5[a]	670.4[a]	200.4[a]	311.1[a]	255.8[a]
1:0	218.2[a]	942.0a[b]	580.1[ab]	213.8[a]	555.6[a]	384.7[a]
0:1	197.3[a]	431.1[b]	314.2[b]	192.4[a]	255.6[a]	223.9[a]

1. Weeks after sowing; 2. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

Table 2. Effect of cropping patterns on weed density.

Treatment	Weed density/m^2					
	6WAS[1]			12WAS		
	2015	2016	Mean	2015	2016	Mean
1:1	27.3[a]	36.3[a2]	31.8[a]	25.0[ab]	22.7[b]	23.8[a]
1:2	31.3[a]	31.0[a]	31.1[a]	29.3[a]	19.3[b]	24.3[a]
2:1	15.3[a]	34.3[a]	24.8[a]	17.0[b]	37[ab]	27.0[a]
2:2	30.7[a]	26.7[a]	28.7[a]	20.0[ab]	39.0[ab]	29.5[a]
1:0	25.0[a]	28.7[a]	26.8[a]	18.3[ab]	57.3[a]	37.8[a]
0:1	32.0[a]	30.0[a]	31.0[a]	20.3[ab]	19.7[b]	20.0[a]

1. Weeks after sowing; 2. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

The effect of cropping patterns on plant height, 100-seed weight and grain yield of maize

Plant height of maize did not significantly differ among the treatments (Table 3). Similarly, 100-seed weight was not significantly influenced by cropping patterns. However, sole maize (1:0) produced significantly higher grain yield than the other treatments but was comparable only to the 2:1 ratio of maize to soybean cropping pattern in both years and the mean.

Table 3. Effect of cropping patterns on maize plant height.

Treatment	Plant height (cm)					
	6WAS[1]			12WAS		
	2015	2016	Mean	2015	2016	Mean
1:1	52.6[a2]	85.3[a]	68.9[a]	209.1[ab]	171.9[a]	190.5[a]
1:2	55.7[a]	91.3[a]	73.5[a]	210.3[ab]	165.4[a]	187.9[a]
2:1	53.9[a]	103.3[a]	78.5[a]	221.9[a]	175.3[a]	198.6[a]
2:2	55.8[a]	102.4[a]	79.1[a]	209.3[ab]	173.4[a]	191.3[a]
1:0	56.5[a]	100.9[a]	78.7[a]	200.6[b]	171.9[a]	186.3[a]
0:1	-	-	-	-	-	-

1. Weeks after sowing; 2. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

Other cropping patterns produced significantly lower yields (Table 4). This could be attributed to the greater plant population of maize in these treatments. Tunku and Ishaya (2012) reported that the higher yield of the sole maize crop could be attributed to higher population of the crop and to the lack of inter-specific competition as a result of the absence of soybean.

Table 4. Effect of cropping patterns on 100-seed weight and grain yield of maize.

Treatment	Grain yield (kg/ha)			Seed weight (g)		
	2015	2016	Mean	2015	2016	Mean
1:1	2,727.3[bc]	1,016.6[a1]	1,871.9[bc]	24.9[a]	21.6[a]	23.3[a]
1:2	1,160.7[d]	1,077.2[a]	1,118.9[c]	25.1[a]	22.9[a]	24.0[a]
2:1	3,597.7[ab]	1,778.9[a]	2,688.3[ab]	25.6[a]	20.9[a]	23.2[a]
2:2	2,195.7[cd]	852.1[a]	1,523.9[c]	25.0[a]	22.2[a]	23.6[a]
1:0	4,620.7[a]	1,298.2[a]	2,959.4[a]	24.8[a]	20.9[a]	22.9[a]
0:1	-	-	-	-	-	-

1. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

Similarly, Oyewole and Magaji (2006) attributed the significant increase in the mean yield of millet in sole millet than in the intercrop treatments of millet and cowpea to higher population of the millet crop and the lack of inter-specific competition as a result of the absence of cowpea. Also, the higher yield of maize in the 2:1 ratio of maize to soybean cropping pattern could be due to the stronger competitive ability of maize for growth resources especially light and the reduced inter-specific competition with soybean. Light has been identified as the major factor for low dry matter production in intercrops (Reddy et al., 1990). This result contrasts with that of Tunku and Ishaya (2012), who recommended the 1:2 ratio of maize to soybean cropping pattern as the best combination for good weed control, growth and yield of maize and soybean intercrop.

The effect of cropping patterns on plant height of soybean

Cropping patterns had no significant effect on plant height of soybean at 6 WAS. However, its effect was significant on this parameter at 12 WAS in 2015, as the 1:1 ratio of maize to soybean cropping pattern had significantly taller soybean than sole soybean treatment, but was comparable with other treatments (Table 5).

Table 5. Effect of cropping patterns on soybean plant height.

Treatment	Plant height (cm)					
	6WAS[1]			12WAS		
	2015	2016	Mean	2015	2016	Mean
1:1	25.8[a2]	36.8[a]	31.3[a]	61.2[a]	55.8[a]	58.1[a]
1:2	23.2[a]	37.4[a]	30.3[a]	58.3[ab]	60.1[a]	59.2[a]
2:1	24.2[a]	34.1[a]	29.1[a]	54.8[ab]	55.6[a]	55.2[a]
2:2	23.5[a]	35.1[a]	29.7[a]	58.4[ab]	54.9[a]	56.6[a]
0:1	22.5[a]	30.5[a]	26.5[a]	49.0[b]	58.1[a]	53.6[a]
1.0	-	-	-	-		

1. Weeks after sowing; 2. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

The effect of cropping patterns on the number of pods/plant and grain yield of soybean and LER

Sole soybean (0:1) produced the highest number of pods, which was comparable with the other treatments except the 1:1 ratio of maize to soybean which produced a significantly lower number of pods/plant in 2015. The number of pods/plant was not significantly affected in 2016 nor was the mean (Table 6). Sole soybean produced grain yield that was significantly higher than the grain yield of

other treatments, but was comparable to the 1:2 ratio of maize to soybean cropping pattern in both years and to the means. The cropping pattern of the 2:1 ratio of maize to soybean, the 2:2 ratio of maize to soybean and the 1:1 ratio of maize to soybean, produced significantly less soybean grain yield at the mean. The 2:1 ratio of maize to soybean cropping system had the highest land equivalent ratio followed by the 1:1 ratio of maize to soybean in both years (Table 7). The higher population of soybean in the sole crop and in the 1:2 ratio of maize to soybean cropping system could have resulted in significantly higher soybean grain yield in both years and in the means.

Table 6. Effect of cropping patterns on the number of pods.

Treatment	2015	2016	Mean
1:1	68.2[b]	60.1[a1]	64.1[a]
1:2	89.3[a]	61.7[a]	75.5[a]
2:1	86.8[a]	57.1[a]	72.0[a]
2:2	84.7[ab]	53.3[a]	68.0[a]
0:1	96.1[a]	60.0[a]	78.0[a]
1.0	-	-	-

1. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

Table 7. Effect of cropping patterns on grain yield of soybean and land equivalent ratio (LER).

Treatment	Grain yield (Kg/ha)			Land equivalent ratio	
	2015	2016	Mean	2015	2016
1:1	1,097.4[a1]	732.5[a]	860.1[b]	1.3	1.1
1:2	1,636.9[a]	1,353.8[a]	1,413.4[ab]	1.3	0.6
2:1	773.8[a]	496.1[a]	596.2[b]	1.3	1.5
2:2	877.7[a]	911.8[a]	850.9[b]	1.0	0.9
0:1	1,610.9[a]	3,681.3[a]	2,565.6[a]	-	-
1:0	-	-	-	-	-

1. Means within the same column with the same letter (s) are not significantly different at the 5% level of probability using the LSD test.

Also, sole soybean was exposed to the greater amount of solar radiation which is an essential factor for photosynthesis and higher yield. This is in line with the findings of Tunku and Ishaya (2012) who reported that the highest grain yield of soybean could be attributed to the higher population of soybean and the lack of inter-specific competition as a result of the absence of maize. The lower yield of

soybean in the intercrop plots with regards to the 1:1 ratio of maize to soybean, the 2:1 ratio of maize to soybean and the 2:2 ratio of maize to soybean could be due to the shade cast on them by the maize crop depriving them of enough sunlight for photosynthesis, dry matter production and good yield.

Economic assessment of cropping patterns

Table 8 presents the economic assessment of cropping patterns in the production of a maize/soybean intercrop. The 2:2 ratio of maize to soybean cropping pattern resulted in the higher combined yield (3,284.5 kg/ha) than the rest of the treatments followed by the sole maize cropping pattern (2,959.4 kg/ha), while the cropping pattern with the lowest yield was combined 2:2 ratio of maize to soybean cropping pattern (2,374.8 kg/ha). The least expensive cropping pattern was sole soybean (₦ 69,000.00 /ha) while the most expensive was the 2:2 ratio of maize to soybean cropping pattern (₦132,500.00). Sole soybean was the most economical cropping system compared to the other treatments. This could be due to the low amount of NPK fertilizer used for its production which brought down the cost of production, while the most expensive cropping system was the 2:2 ratio of maize to soybean. The cropping pattern which generated the highest revenue/income (₦ 549,368.00) was the 2:1 ratio of maize to soybean cropping pattern, followed by sole maize (₦ 513,120.00), while the lowest revenue generating cropping pattern (₦473,504.00) was the 2:2 ratio of maize to soybean. The cropping pattern that gave the highest profit was sole soybean (₦ 444,120.00/ha) followed by the 2:1 ratio of maize to soybean cropping pattern (₦ 419,701.04/ha), while the 2:2 maize soybean cropping pattern had the lowest profit/ha (₦281,504) (Table 8). The highest income generated by the 2:1 ratio of maize to soybean cropping pattern could have resulted from the combined income generated from maize and soybean. Soybean has higher price value than maize in the Ilorin market. Despite this advantage, sole soybean was more profitable than the 2:1 ratio of maize to soybean cropping system. This is a result of the lower cost of producing sole soybean. In the production of maize, sole maize had the lowest cost:benefit ratio (1:0.270) followed by the 2:1 ratio of maize to soybean cropping pattern (1:0.277). To produce only soybean, the cropping pattern with the highest cost:benefit ratio (1:0.663) was the 2:1 ratio of maize to soybean while sole soybean had the lowest cost:benefit ratio (1:0.134). The cost:benefit ratio of the combined yield of maize and soybean was the lowest with the 2:1 ratio of maize to soybean cropping system (1:0.236). Although this was less beneficial than the sole soybean cropping system, the highest cost:benefit ratio was incurred by the cropping pattern in the 2:2 ratio of maize to soybean. The 2:1 ratio of maize to soybean had lower combined cost:benefit ratio than sole maize and other treatments except for sole soybean which had the lowest cost:benefit ratio. This is

an indication that these cropping systems are more cost-effective and financially beneficial than sole maize. Similarly, the 2:1 cropping pattern had the highest land equivalent ratio (LER) of 1.30 and 1.50 in 2015 and 2016 respectively. This indicates that the 2:1 stand proportion in the intercrop had greater yield advantage of 30 and 50% than sole cropping. A higher LER in intercropping than in mono-cropping has been reported in maize/pigeon pea (Patra et al., 1990), maize/soybean (Kalia et al., 1992), and maize/groundnut (Madimba, 1995).

Table 8. Economic assessment of cropping patterns in the production of a maize/soybean intercrop.

	Cropping pattern					
Crop yield (kg/ha)	1	2	3	4	5	6
Maize	1,871.9	1,118.9	2,688.3	1,523.9	2,959.4	-
Soybean	860.1	1,413.4	596.2	850.9	-	
Combined	2,732	2,532.3	3,284.5	2,374.8	2,959.4	2,565.6
Cost of production (₦)						
Maize	118,750	118,750	119,166.6	122,000.00	128,000	-
Soybean	10,500	11,333.3	10,500.00	10,500.00	-	69,000
Combined	129,250	130,083.3	129,666.6	132,500.00	128,000	69,000
Total revenue (₦)						
Maize	299,504	179,024	430,128	243,824	473,504	-
Soybean	172,020	282,680	119,240	170,180	-	513,120
Combined	471,524	461,704	549,368	414,004	473,504	513,120
Profit/gross margin	342,274	331,620.7	419,701.4	281,504	345,504	444,120
Cost:benefit ratio						
Maize	1:0.396	1:0.663	1:0.277	1:0.500	1:0.270	-
Soybean	1:0.061	1:0.040	1:0.088	1:0.061	-	1:0.134
Combined	1:0.214	1:0.281	1:0.236	1:0.320`	-	-

Average market prices in Ilorin, 2016/2017, for maize = ₦160/kg, soybean = ₦200/kg: 1 = 1:1; 2 = 1:2; 3 = 2:1; 4 = 2:2; 5 = 1:0; 6 = 0:1.

Conclusion

In conclusion, the type of a cropping system to recommend to the farmers depends on the objectives of the farmer. If his/her objective is to diversity food supply as well as to generate revenue and minimize weed infestation, the 2:1 ratio of maize to soybean cropping system will be more suitable. However, if the objective is to minimize weed infestation, especially in an intensively cultivated field where other crops will follow soybean production in the crop rotation and for profitability, sole soybean could be adopted.

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ZAKOROVLJENOST I PRODUKTIVNOST ZDRUŽENOG USEVA KUKURUZA I SOJE U ZAVISNOSTI OD RASPOREDA BILJAKA U SAVANI JUŽNE GVINEJE U NIGERIJI

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R e z i m e

Poljski ogledi su sprovedni tokom 2015. i 2016. godine na nastavno-istraživačkom gazinstvu Poljoprivrednog koledža, Univerziteta u Kvari, Malete, kako bi se odredio uticaj prostornog rasporeda biljaka na zakorovljenost, rast i prinos združenog useva kukuruza i soje u savani južne Gvineje u Nigeriji. Ogledi su se sastojali od sledećih šest tretmana: jedan red kukuruza naizmenično sa jednim redom soje (1:1), jedan red kukuruza naizmenično sa dva reda soje (1:2), dva reda kukuruza naizmenično sa jednim redom soje (2:1), dva reda kukuruza naizmenično sa dva reda soje (2:2), čist usev kukuruza (1:0) i čist usev soje (0:1). Tretmani su bili postavljeni u potpunom slučajnom blok sistemu u tri ponavljanja. Prikupljeni podaci su obrađeni analizom varijanse i srednje vrednosti su poređene korišćenjem testa najmanje značajnih razlika (LSD) pri 5% nivou verovatnoće. Rezultati su pokazali da čist usev soje dosledno potiskuje korove što vodi ka većem prinosu. Pored toga, odnos 2:1 kukuruza prema soji nije samo smanjio gustinu korova, već je značajno povećao prinos kukuruza i smanjio prinos soje. Isti tretman je pokazao višu efikasnost korišćenja zemljišta i ekonomski prinos, a pratio ga je čist usev kukuruza.

Ključne reči: združeni usev, prinos useva/visina useva, ekonomski prinosi, efikasnost korišćenja zemljišta, Nigerija, gustina korova.

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FENOLOŠKE OSOBINE, RODNOST I KVALITET PLODA SORTI ŠLJIVE SREDNJE POZNOG VREMENA ZRENJA NA PODRUČJU BEOGRADA

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Sažetak: U periodu od pet godina (2013–2017) na području Beograda ispitivane su fenološke osobine, rodnost i kvalitet ploda 14 sorti šljive srednje poznog vremena zrenja. Kao standard za poređenje je uzeta sorta Čačanska rodna. Prosečno vreme cvetanja je bilo u prvoj polovini aprila, a zrenja plodova u prvoj polovini avgusta. Najmanji prinos po stablu imala je sorta Nevena (1,6 kg), a najviši sorta Mildora (22,5 kg). Statistički značajno niži prinos u odnosu na standard imalo je sedam sorti. Najmanja bujnost je utvrđena kod standard sorte (Čačanska rodna), a najveća kod sorte Milka. Prosečna masa ploda je iznosila od 19,5 g (Nevena) do 50,5 g (Valor). U poređenju sa kontrolom, masa ploda je bila statistički značajno veća kod pet sorti. Sve sorte su imale visok sadržaj rastvorljive suve materije (iznad 17%), dok je kod sorti Mildora i Valor on bio značajno viši u odnosu na kontrolu. Na osnovu rezultata istraživanja, za gajenje se mogu preporučiti sledeće sorte: Valor i Čačanska najbolja kao pretežno stone sorte, Jojo i Vengerka krupna slatka kao sorte kombinovanih svojstava, i Mildora kao sorta za preradu.

Ključne reči: *Prunus domestica*, cvetanje, zrenje, prinos, osobine ploda.

Uvod

Šljiva je po broju stabala i proizvodnji najznačajnija vrsta voćaka u Srbiji. Sa godišnjom proizvodnjom od 415.093 t (prosek 2012–2016. godine), Srbija zauzima treće mesto u svetu, iza Kine i Rumunije. Međutim, u proizvodnji šljive se sreću mnogi problemi kao što su: veliki udeo starih i zapuštenih zasada sa ekstenzivnom proizvodnjom i slabom primenom agrotehničkih i pomotehničkih mera, široka rasprostranjenost šarke šljive, veliki udeo rakijskih sorti lošijeg kvaliteta i manje upotrebne vrednosti plodova, kao i nizak nivo tehnologije prerade. Zbog navedenih razloga, prosečan prinos šljive je mali i iznosi 5,3 t/ha (Republički zavod za statistiku RS, 2017).

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Na oplemenjivanju šljive (*Prunus domestica* L.) se najviše radi u Evropi. U 13 evropskih zemalja, u okviru 21 oplemenjivačkog programa, u poslednjih 20 godina je realizovano više od 170 novostvorenih sorti šljive (Butac et al., 2013). Najvažniji ciljevi oplemenjivanja su: adaptivnost na različite ekološke uslove, visoka rodnost, produžetak raspona sazrevanja, dobar kvalitet ploda (krupnoća, tamnoplava boja ploda, žuta boja mesa, čvrstoća mesa, lako odvajanje od koštice), kao i otpornost na prouzrokovače bolesti, naročito na virus šarke šljive (Neumüller, 2010). Najznačajniji programi oplemenjivanja domaće šljive se nalaze u Nemačkoj, Srbiji, Rumuniji i Bugarskoj.

U Srbiji se oplemenjivanje šljive odvija u Institutu za voćarstvo u Čačku, gde je do sada stvoreno 15 novih sorti (Lukić et al., 2016). Najviše gajene domaće sorte u Srbiji su Čačanska rodna i Čačanska lepotica. Među novije priznatim sortama je Mildora, koja se odlikuje vrlo visokim sadržajem suve materije (preko 20%), što je čini pogodnom za sušenje (Ogašanović et al., 2005).

Od sorti stvorenih u Nemačkoj, posebno se ističe Jojo, kao prva sorta potpuno otporna na virus šarke šljive, čija se otpornost bazira na mehanizmu hipersenzitivnosti (Hartmann, 2007). U Bugarskoj se na oplemenjivanju šljive radi u institutima u Drjanovu, Trojanu, Ćustendilu, Sofiji i Plovdivu i do sada je stvoreno 29 novih sorti, među kojima su i Gabrovska, Strinava i Nevena (Zhivondov et al., 2012).

Introdukcija novih sorti može doprineti poboljšanju sortimenta šljive u Srbiji. Pre uvođenja u proizvodnju treba ispitati adaptivnost novointrodukovanih sorti na naše agroekološke uslove.

Cilj ovog rada je bilo ispitivanje fenoloških osobina, prinosa i kvaliteta ploda kod većeg broja sorti šljive srednje poznog vremena sazrevanja. Na osnovu dobijenih rezultata, najbolje sorte će se preporučiti za gajenje u beogradskom Podunavlju, kao i u drugim regionima sa sličnim ekološkim uslovima.

Materijal i metode

Istraživanja su obavljena u kolekcionom zasadu šljive na Oglednom dobru „Radmilovac" Poljoprivrednog fakulteta u Beogradu, u petogodišnjem periodu (2013–2017). Eksperimentalni zasad je posađen 2009. godine, tako da su stabla u periodu ispitivanja bila starosti pet do devet godina. Kao podloga su korišćeni sejanci džanarike (*Prunus cerasifera* Ehrh.). Razmak sađenja je 4,5 m × 3 m, što odgovara gustini sklopa od 740 stabala po hektaru. Od svake sorte u kolekcionom zasadu je posađeno po pet stabala. U zasadu se primenjuju standardne agrotehničke mere, bez navodnjavanja.

Ispitivano je 14 sorti evropske šljive srednje poznog vremena sazrevanja. Četiri sorte potiču iz Srbije: Čačanska najbolja, Mildora, Zlatka i Čačanska rodna (koja je uzeta kao standard), tri sorte su iz Bugarske (Gabrovska, Nevena i

Strinava), dve iz Ukrajine (Vengerka jubilejna i Vengerka krupna slatka), a po jedna iz Velike Britanije (Avalon), Nemačke (Jojo), Češke (Milka), Francuske (Primakot) i Kanade (Valor).

Početak cvetanja je registrovan kada se otvori 10% cvetova na stablu, puno cvetanje kada se otvori 80% cvetova, a kraj cvetanja kada otpadne 90% kruničnih listića (Wertheim, 1996). Kao vreme zrenja su uzeti datumi početka berbe.

Prinos je određen merenjem mase ubranih plodova. Kumulativni koeficijent rodnosti je izračunat iz odnosa kumulativnog prinosa po stablu u periodu ispitivanja (2013–2017) i površine poprečnog preseka debla u poslednjoj godini (2017) i izražen je u kg po cm^2. Površina poprečnog preseka debla je preračunata na osnovu merenja obima debla (na visini od 30 cm iznad mesta kalemljenja).

Za određivanje osobina ploda korišćen je uzorak od 25 plodova od svake sorte. Indeks oblika ploda je izračunat pomoću formule: $dužina^2/širina \times debljina$. Rastvorljive suve materije su određivane pomoću refraktometra (Pocket PAL-1, Atago, Japan). Ukupne kiseline su određene metodom titracije sa natrijum hidroksidom i iskazane su kao jabučna kiselina. Petočlani žiri ocenjivao je senzorički izgled i ukus ploda, davanjem ocena od 1 do 5.

Dobijeni podaci obrađeni su statistički pomoću metode analize varijanse. Značajnost razlika između srednjih vrednosti utvrđena je pomoću Dankanovog testa višestrukih intervala za verovatnoću 0,05.

Rezultati i diskusija

Ispitivane sorte šljive su prosečno cvetale u prvoj polovini aprila (tabela 1). Cvetanje je bilo najranije kod sorti Jojo i Valor, a najkasnije kod sorte Nevena. Razlika u prosečnom datumu početka cvetanja između sorti je bila pet dana, a po godinama je varirala 3–10 dana.

Cvetanje je bilo najranije u 2014. godini, kada je prosečan datum početka cvetanja bio 25. mart. Najkasnije cvetanje je bilo u 2013. godini, kada je počelo u proseku 17. aprila. Prosečna razlika u početku cvetanja između godina je bila 23 dana. Ona je bila znatno veća nego razlika između sorti. Na osnovu toga se može zaključiti da na fenofazu cvetanja šljive više utiču ekološki faktori (prvenstveno temperatura), nego genetske karakteristike sorti. To je u skladu sa rezultatima dobijenim kod kajsije (Milatović, 2005).

Prosečno trajanje cvetanja je iznosilo 8,6 dana i variralo je od 7,0 dana kod sorte Nevena do 10,2 dana kod sorti Jojo i Valor. Po godinama, prosečno trajanje cvetanja je variralo od 7,1 dan (2015) do 9,9 dana (2016). Cvetanje je trajalo duže kod sorti sa ranijim vremenom cvetanja, kao i u godinama sa ranijim početkom cvetanja i nižim temperaturama u toku ove fenofaze.

Prosečna obilnost cvetanja je bila najmanja kod sorte Nevena (ocena 2,4 na skali 0−5). S druge strane, najobilnije cvetanje je zabeleženo kod sorte Gabrovska (ocena 4,5).

Tabela 1. Fenološke karakteristike sorti šljive (prosek, 2013–2017. godine).
Table 1. Phenological characteristics of plum cultivars (average, 2013–2017).

Sorta *Cultivar*	Datumi cvetanja *Flowering dates*			Trajanje cvetanja (dani) *Duration of flowering (days)*	Obilnost cvetanja (skala 0−5) *Abundance of flowering (0−5 scale)*	Datumi berbe *Harvest dates*
	Početak *Start*	Puno *Full*	Kraj *End*			
Avalon	04.04.	06.04.	10.04.	7,2	4,0	05.08.
Čačanska najbolja	02.04.	05.04.	10.04.	9,0	4,0	07.08.
Čačanska rodna (kontrola)	02.04.	04.04.	09.04.	8,4	4,4	10.08.
Gabrovska	03.04.	05.04.	09.04.	7,4	4,5	03.08.
Jojo	01.04.	04.04.	10.04.	10,2	3,8	13.08.
Mildora	03.04.	05.04.	10.04.	8,2	3,7	12.08.
Milka	03.04.	05.04.	11.04.	9,0	3,1	06.08.
Nevena	06.04.	07.04.	12.04.	7,0	2,4	15.08.
Primakot	03.04.	05.04.	10.04.	8,6	4,3	08.08.
Strinava	03.04.	05.04.	10.04.	9,0	4,1	14.08.
Valor	01.04.	03.04.	10.04.	10,2	3,7	08.08.
Vengerka jubilejna	03.04.	05.04.	11.04.	10,0	3,5	04.08.
Vengerka krupna slatka	02.04.	05.04.	09.04.	8,4	4,1	10.08.
Zlatka	05.04.	07.04.	12.04.	8,2	3,4	10.08.

Prosečno vreme zrenja ispitivanih sorti šljive je bilo u prvoj polovini avgusta. Zrenje je bilo najranije kod sorte Gabrovska, a najkasnije kod sorte Nevena. Razlika između godina sa najranijim i najkasnijim datumom berbe je iznosila prosečno 10 dana, a po sortama je varirala od tri dana (Milka) do 16 dana (Primakot i Zlatka).

Cvetanje i zrenje sorti šljive na području Beograda je bilo ranije u poređenju sa istim sortama u uslovima Češke (Blažek i Pišteková, 2009), centralne Bugarske (Dragoyski et al., 2010) i severne Crne Gore (Božović i Jaćimović, 2012). Ove razlike su posledica različitih klimatskih karakteristika lokaliteta ispitivanja.

Prosečan prinos po stablu je bio najniži kod sorte Nevena (1,6 kg), a najviši kod sorte Mildora (22,5 kg) (tabela 2). U poređenju sa kontrolom (sorta Čačanska rana), statistički značajno manji prinos je dobijen kod sedam sorti (Nevena, Avalon, Primakot, Milka, Vengerka jubilejna, Gabrovska i Zlatka). Po visokom prinosu (iznad 20 kg po stablu) ističu se sorte Mildora, Valor, Čačanska najbolja i Jojo.

Izuzetno nizak prinos (prosečno 1,6 kg po stablu) dobijen je kod bugarske sorte Nevena. To je u suprotnosti sa rezultatima koje navode Ivanova et al. (2014) da je ova sorta umerene rodnosti sa prosečnim prinosom od 50 kg po stablu, koji je dobijen u Bugarskoj u zasadu starosti 9–13 godina. Pored različitih agroekoloških uslova i manje starosti stabala u našem istraživanju, mogući razlog za to je što je

ova sorta samobesplodna (Vitanova et al., 1998). Pored toga, ona cveta najkasnije od svih ispitivanih sorti, pa je moguće da u oglednom zasadu ne postoje odgovarajući oprašivači sa dobrim preklapanjem u vremenu cvetanja.

Tabela 2. Prinos, površina poprečnog preseka debla (PPPD) i kumulativni koeficijent rodnosti (KKR) sorti šljive.
Table 2. Yield, trunk cross-sectional area (TCSA), and cumulative yield efficiency (CYE) of plum cultivars.

Sorta *Cultivar*	Prinos (kg po stablu) *Yield (kg per tree)*						PPPD *TCSA* (cm^2)	KKR *CYE* (kg/cm^2)
	2013	2014	2015	2016	2017	Mx		
Avalon	6,5	7,9	12,7	2,1	14,0	8,6 d	118,0 bc	0,37
Čačanska najbolja	14,9	23,5	32,3	17,6	17,2	21,1 ab	144,5 b	0,73
Čačanska rodna (kontrola)	8,5	15,6	21,6	32,6	13,6	18,4 ab	69,9 d	1,31
Gabrovska	8,3	14,3	17,9	6,4	13,2	12,0 cd	103,2 cd	0,58
Jojo	15,4	27,5	20,0	28,2	14,6	21,1 ab	137,1 bc	0,77
Mildora	12,3	23,5	5,3	30,6	40,8	22,5 a	134,5 bc	0,84
Milka	3,6	27,7	11,9	0,7	12,4	11,3 cd	197,5 a	0,29
Nevena	1,2	0,6	3,6	0,1	2,2	1,6 e	126,1 bc	0,06
Primakot	5,7	14,8	6,2	15,3	9,5	10,3 cd	113,8 bc	0,45
Strinava	8,5	16,3	8,7	28,7	16,5	15,7 bc	120,3 bc	0,65
Valor	5,9	27,5	13,1	45,6	18,1	22,0 a	128,7 bc	0,86
Vengerka jubilejna	1,3	25,8	0,1	19,1	12,3	11,7 cd	101,0 cd	0,58
Vengerka krupna slatka	6,1	28,5	7,4	37,7	14,4	18,8 ab	143,8 b	0,65
Zlatka	2,7	10,4	11,2	19,3	17,9	12,3 cd	105,3 cd	0,58

Srednje vrednosti označene istim slovom u okviru jedne kolone ne razlikuju se značajno prema Dankanovom testu višestrukih intervala za verovatnoću 0,05.

Mean values followed by the same letter within a column do not differ significantly according to Duncan's multiple range test at P≤0.05.

Po godinama ispitivanja, najniži prinos je zabeležen u 2013. godini. To je bilo i očekivano, s obzirom na to da je starost zasada tada bila pet godina, što znači da je on još bio u periodu početne rodnosti. Najviši prinos je postignut u 2014. i 2016. godini (prosečno 18,9 odnosno 20,3 kg po stablu). U periodu ispitivanja u oglednom zasadu nisu zabeleženi jaki zimski mrazevi, kao ni pozni prolećni mrazevi koji bi mogli dovesti do izmrzavanja generativnih organa šljive. Nešto niži prinos koji je dobijen u 2015. i 2017. godini (prosečno 12,3 odnosno 15,5 kg po stablu) može se objasniti pojavom alternativnosti u rađanju, tj. visoke rodnosti pojedinih sorti u prethodnoj godini.

Među ispitivanim sortama najmanju bujnost izraženu preko površine poprečnog preseka debla (PPPD) imala je standard sorta – Čačanska rodna. Većina ispitivanih sorti (deset) je imala statistički značajno veću PPPD u odnosu na

standard sortu. Najveću bujnost je imala sorta Milka, kod koje je PPPD bila statistički značajno veća u odnosu na sve ostale sorte.

Koeficijent rodnosti je značajan pokazatelj koji objedinjuje rodnost i bujnost sorti. Kumulativni koeficijent rodnosti (KKR) je bio najviši kod standard sorte (Čačanska rodna) i iznosio je 1,31 kg/cm^2. Iako je ova sorta po rodnosti bila rangirana tek na petom mestu, u pogledu KKR je bila ubedljivo prva, zahvaljujući maloj bujnosti. Na osnovu niskih vrednosti za PPPD i KKR, ova sorta se može preporučiti za gajenje u gustoj sadnji. To je u skladu sa rezultatima koje su dobili drugi autori (Blažek et al., 2004; Milošević i Milošević, 2011; Glišić et al., 2015).

Prosečna masa ploda je iznosila od 19,5 g kod sorte Nevena do 50,5 g kod sorte Valor (tabela 3). U poređenju sa kontrolom, masa ploda je bila statistički značajno veća kod pet sorti (Valor, Čačanska najbolja, Milka, Jojo i Vengerka krupna slatka).

Tabela 3. Karakteristike ploda sorti šljive (prosek, 2013–2017. godine).
Table 3. Fruit characteristics of plum cultivars (average, 2013–2017).

Sorta *Cultivar*	Masa ploda *Fruit weight* (g)	Masa koštice *Stone weight* (g)	Udeo koštice *Stone share* (%)	Dimenzije ploda (cm) *Fruit dimensions (cm)*			Indeks oblika *Shape index*	Dužina peteljke *Stalk length* (cm)
				Dužina *Length*	Širina *Width*	Debljina *Thickness*		
Avalon	26,0 d	1,52 cd	5,8	4,4 bc	3,1 de	3,2 e	1,93	1,8 bcd
Čačanska najbolja	42,0 b	2,04 a	4,9	4,7 ab	3,8 b	3,8 abc	1,53	1,7 cde
Č. rodna (kontrola)	25,4 d	1,24 e	4,9	4,3 cd	3,2 de	3,5 cde	1,64	2,3 a
Gabrovska	28,0 d	1,28 de	4,6	4,5 bc	3,2 de	3,3 de	1,89	1,5 ef
Jojo	34,8 c	1,89 ab	5,4	4,7 ab	3,5 bcd	3,5 cde	1,83	1,3 fg
Mildora	25,5 d	1,15 ef	4,5	3,9 de	3,3 d	3,2 e	1,40	1,1 g
Milka	34,9 c	1,70 bc	4,9	4,5 bc	3,4 cd	3,6 bcd	1,66	1,7 cde
Nevena	19,5 e	0,95 fg	4,9	3,8 e	2,8 e	2,8 f	1,79	1,6 def
Primakot	24,2 de	0,92 g	3,8	4,2 cde	3,1 de	3,2 e	1,73	2,1 ab
Strinava	26,6 d	1,18 e	4,4	4,3 bc	3,2 de	3,2 e	1,79	2,2 a
Valor	50,5 a	1,96 a	3,9	5,0 a	4,3 a	4,1 a	1,43	1,9 abc
Vengerka jubilejna	41,8 b	1,50 cd	3,6	4,7 ab	3,7 bc	3,9 ab	1,55	1,0 g
Veng. krupna slatka	33,8 c	1,25 e	3,7	4,6 abc	3,5 bcd	3,6 bcd	1,70	1,7 cde
Zlatka	27,2 d	0,88 g	3,2	4,4 bc	3,2 de	3,3 e	1,88	1,7 cde

Srednje vrednosti označene istim slovom u okviru jedne kolone ne razlikuju se značajno prema Dankanovom testu višestrukih intervala za verovatnoću 0,05.

Mean values followed by the same letter within a column do not differ significantly according to Duncan's multiple range test at P≤0.05.

Po godinama ispitivanja, masa ploda je bila značajno veća u 2014. i 2016. godini u odnosu na preostale tri godine. To se može objasniti većom količinom padavina u ove dve godine u periodu razvoja plodova šljive. Suma

padavina u periodu april–avgust u 2014. godini je bila 624 mm, a u 2016. godini 366 mm. U preostale tri godine, suma padavina u ovom periodu je bila znatno manja (187–287 mm).

Masa koštice je bila u intervalu od 0,88 g (Zlatka) do 2,04 g (Čačanska najbolja). Udeo koštice u masi ploda je iznosio od 3,2% (Zlatka) do 5,8% (Avalon).

Između ispitivanih sorti utvrđene su značajne razlike u dimenzijama ploda. Najkrupnije plodove imala je sorta Valor, a najsitnije sorta Nevena. Krupnoća ploda je veoma značajna osobina kod sorti koje su namenjene za potrošnju u svežem stanju. Od ispitivanih sorti za stonu potrošnju su najpogodnije sorte Valor, Čačanska najbolja i Vengerka krupna slatka koje se ističu po krupnoći ploda.

Na osnovu dimenzija ploda izračunat je indeks oblika (IO) ploda, čije su vrednosti iznosile od 1,40 do 1,93. Na osnovu IO možemo zaključiti da su sve ispitivane sorte imale izdužen oblik. Sa izuzetkom sorte Mildora koja je imala ovalan oblik, ostale sorte su imale eliptičan oblik ploda. Peteljka ploda je bila najkraća kod sorte Vengerka jubilejna (1,0 cm), a najduža kod standard sorte – Čačanska rodna (2,3 cm).

Rezultati dobijeni za osobine ploda u ovom radu su u saglasnosti sa prethodno objavljenim rezultatima za pojedine sorte (Blažek et al., 2004; Dragoyski et al., 2010; Milošević i Milošević, 2011; Glišić et al., 2015). Vrednosti u ovom istraživanju su bile nešto niže u odnosu na vrednosti koje su dobili Hodun et al. (1998) u uslovima Poljske, kao i Kemp i Wustenberghs (1998) u uslovima Holandije.

Sve ispitivane sorte su imale visok sadržaj rastvorljive suve materije (iznad 17%). Kod sorti Mildora i Valor on je bio statistički značajno viši u odnosu na kontrolu (tabela 4).

Značajne razlike u pogledu ovog parametra su ispoljene i po godinama istraživanja. Sadržaj rastvorljive suve materije (RSM) je bio najviši (prosečno 21,1% za sve sorte) u 2015. godini koja se odlikovala najmanjom sumom padavina u periodu razvoja ploda (IV–IX, 187 mm). S druge strane, najniži sadržaj RSM (prosečno 16,1%) je zabeležen u 2014. godini koja je imala najveću sumu padavina u navedenom periodu (624 mm).

Sadržaj ukupnih kiselina (UK) je varirao od 0,52% kod sorte Vengerka krupna slatka do 1,18% kod sorte Valor. Značajno viši sadržaj UK u odnosu na standard je imalo pet sorti (Valor, Nevena, Jojo, Primakot i Strinava).

Utvrđeno je da je za prihvatanje sorti šljive od strane potrošača značajniji odnos između sadržaja rastvorljive suve materije i ukupnih kiselina (RSM/UK) nego sam sadržaj RSM (Crisosto et al., 2004). Vrlo visok odnos RSM/UK (iznad 30) su imale sorte Mildora, Vengerka krupna slatka i Milka, što ukazuje na njihov izrazito sladak ukus. S druge strane, odnos RSM/UK ispod 20 su imale

sorte Nevena, Jojo, Vengerka jubilejna, Valor i Čačanska najbolja. Za ove sorte karakterističan je slatko-nakiseo ukus.

Tabela 4. Pokazatelji kvaliteta ploda sorti šljive (prosek, 2013–2017. godine).
Table 4. Indices of fruit quality of plum cultivars (average, 2013–2017).

Sorta *Cultivar*	Rastvorljiva suva materija *Soluble solids* (%)	Ukupne kiseline *Total acids* (%)	RSM/ UK *SS/TA*	Senzorička ocena (1–5) *Sensory evaluation* (1–5)	
				Izgled *Appearance*	Ukus *Taste*
Avalon	17,2 d	0,66 fgh	26,2	3,3 de	4,0 ab
Čačanska najbolja	17,3 cd	0,88 cde	19,6	4,7 a	4,0 ab
Čačanska rodna (kontrola)	19,0 bcd	0,74 efg	25,5	3,4 cde	4,2 a
Gabrovska	18,0 cd	0,73 efg	24,5	4,1 abc	3,8 ab
Jojo	17,1 d	1,05 abc	16,3	4,2 ab	3,7 ab
Mildora	21,9 a	0,58 gh	38,1	2,7 e	4,2 a
Milka	20,5 ab	0,67 fgh	30,6	3,7 bcd	4,0 ab
Nevena	17,2 d	1,13 ab	15,1	3,0 de	3,7 ab
Primakot	19,6 abc	0,97 bcd	20,3	3,4 cde	3,3 b
Strinava	19,2 bcd	0,94 cd	20,5	3,5 bcd	3,9 ab
Valor	21,6 a	1,18 a	18,3	4,6 a	4,2 a
Vengerka jubilejna	18,8 bcd	1,15 ab	16,4	4,2ab	3,7 ab
Vengerka krupna slatka	19,2 bcd	0,52 h	36,8	4,0 abc	3,8 ab
Zlatka	17,8 cd	0,80 def	22,4	3,4 cde	4,0 ab

Srednje vrednosti označene istim slovom u okviru jedne kolone ne razlikuju se značajno prema Dankanovom testu višestrukih intervala za verovatnoću 0,05.

Mean values followed by the same letter within a column do not differ significantly according to Duncan's multiple range test at P≤0.05.

Podaci o hemijskom sastavu plodova su u skladu sa prethodno objavljenim rezultatima za pojedine sorte (Dragoyski et al., 2010; Bozhkova, 2013; Glišić et al., 2015). U odnosu na rezultate koje su dobili Bohačenko et al. (2010) u uslovima Češke, u našem istraživanju je dobijen viši sadržaj RSM i niži sadržaj UK. Dobijene razlike se mogu objasniti toplijom i suvljom klimom u uslovima Srbije. Izuzetno visok sadržaj RSM i nizak sadržaj UK kod sorte Mildora potvrđuje navode Ogašanović et al. (2005) i Mitrović et al. (2006), kao i pogodnost ove sorte za sušenje.

Najbolje ocenjene sorte za izgled ploda bile su Čačanska najbolja i Valor, dok su najviše ocene za ukus dobile sorte Čačanska rodna, Mildora i Valor. Naši rezultati o dobrom ukusu sorte Valor su u skladu sa rezultatima koje navode Kemp i Wustenberghs (1998).

Zaključak

Cvetanje ispitivanih sorti šljive na području Beograda je bilo u prvoj polovini aprila, a zrenje u prvoj polovini avgusta. Po visokoj rodnosti (prosečno preko 20 kg po stablu) ističu se sorte Mildora, Valor, Čačanska najbolja i Jojo. U odnosu na standard sortu (Čačanska rodna), statistički značajno veću masu ploda je imalo pet sorti (Valor, Čačanska najbolja, Milka, Jojo i Vengerka krupna slatka), dok je sadržaj suve materije bio značajno viši kod dve sorte: Mildora i Valor. Na osnovu dobijenih rezultata, za gajenje na području Beograda se mogu preporučiti: Valor i Čačanska najbolja kao pretežno stone sorte, Jojo i Vengerka krupna slatka kao sorte kombinovanih svojstava i Mildora kao sorta za preradu.

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PHENOLOGICAL CHARACTERISTICS, YIELD AND FRUIT QUALITY OF MEDIUM-LATE RIPENING PLUM CULTIVARS IN THE REGION OF BELGRADE

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A b s t r a c t

Phenological characteristics, yield and fruit quality of 14 medium-late ripening plum cultivars, were studied in the region of Belgrade during the five-year period (2013–2017). The control cultivar for comparison was 'Čačanska rodna'. Flowering of tested cultivars occurred in the first half of April, and fruit maturation was in the first half of August. The average yield per tree was the lowest in the 'Nevena' cultivar (1.6 kg), and the highest in the 'Mildora' cultivar (22.5 kg). Compared to the control cultivar, significantly lower yield was achieved in seven cultivars. The lowest vigor was determined in the standard cultivar ('Čačanska rodna'), and the highest in the 'Milka' cultivar. The average fruit weight ranged from 19.5 g in the 'Nevena' cultivar to 50.5 g in the 'Valor' cultivar. Compared to the control, fruit weight was statistically significantly higher in five cultivars. In all studied cultivars, the high soluble solids content (over 17%) was found, while in cultivars 'Mildora' and 'Valor' it was significantly higher than in the control. On the basis of the obtained results, as regards cultivation in the region of Belgrade, it is possible to recommend the following cultivars: 'Valor' and 'Čačanska najbolja' as predominantly table cultivars (for fresh consumption), 'Jojo' and 'Vengerka krupna slatka' as cultivars of combined characteristics and 'Mildora' as a cultivar for processing.

Key words: *Prunus domestica*, flowering, maturation, yield, fruit characteristics.

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SYNERGISTIC EFFECT OF SPINOSAD WITH SELECTED BOTANICAL POWDERS AS BIORATIONAL INSECTICIDES AGAINST ADULTS OF *TRIBOLIUM CASTANEUM* HERBST, 1797 (COLEOPTERA: TENEBRIONIDAE)

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Abstract: The synergistic effect of spinosad with three botanical (*Aframomum melegueta*, *Eugenia aromatica* and *Piper guineense*) powders as biorational insecticides against *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) infesting melon (*Citrullus lanatus*) seeds was investigated. Treatments included sole application of each botanical powder (50 g/kg of melon seed), sole application of spinosad (SASp) (1.0 g/kg), mixture of spinosad (0.5 g/kg) + botanical powders (25 g/kg) and an untreated control. Data were collected on tenebronid mortality rate (%) (PM) and melon seed weight loss rate in % (PWL). Phytochemical analysis of the botanicals was also carried out. At 3−14 days after treatment (DAT), PM observed in melon seeds treated with SASp (90.00−100.00%) was not significantly ($p>0.05$) different from PM observed in melon seeds treated with spinosad + *E. aromatica* powder (86.67−100.00%) and spinosad + *P. guineense* powder (85.00−100.00%). PWL observed in melon seeds treated with spinosad + botanical powders (1.17−1.40%) was not significantly different from PWL observed in seeds treated with SASp (0.42%), but it was significantly lower than PWL (3.28%) observed in melon seeds treated with sole application of *A. melegueta* powder. *P. guineense* powder had the highest contents of alkaloids (868.33 mg/100 g), tannins (550.00 mg/100 g), phenolics (53.57 GAE/g), and steroids (740.00 mg/100 g). *E. aromatica* powder had the highest contents of flavonoids (1466.67 mg/100 g), terpenoids (1276.00 mg/100 g) and cardiac glycosides (7.33 mg/100 g), while *A. melegueta* powder had the highest content of saponins (376.67 mg/100 g). The combination of spinosad with *P. guineense* powder or *E. aromatica* powder performed better than the combination with *A. melegueta* powder and is therefore recommended as a biorational approach for the control of *T. castaneum.*

Key words: red flour beetle, spinosad, seed, synergistic effect, melon, botanical powder.

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Introduction

Melon (*Citrullus lanatus*) is an oil crop cultivated twice in a year in many developing tropical countries. After harvest and post-harvest processing, its seed coat can be removed and the oil-rich seeds can be stored until use. According to Ojeih et al. (2007), melon (egusi) seed is nutritionally rich and is characterized by the following nutrient profile: moisture (4.6%), ash (3.7%), ether extract (45.7%), crude protein (23.4%), crude fibre (12.0%) and total carbohydrate (10.6%); mineral elements: Na, K, Ca, Mg, Mn, Cu, Zn, Fe and P. Essential amino acids which include arginine, isoleucine, leucine and phenylalanine have been identified in melon. This makes it at par with other protein-rich plant foods. In some parts of southwestern Nigeria, its oil commands greater prices than groundnut oils. Despite its nutritionals uses, melon seeds can be attacked by some stored product insects like *Oryzaephilus*, *Tribolium* and *Trogoderma* species. When it is stored with other arable crops in the same storage facility, the tendency of cross-infestation by major insect pests of the companion stored products is not unlikely (Babarinde et al., 2008b).

Tribolium castaneum (Herbst) has been reported to be a major secondary pest of processed or damaged stored cereal products (Lorini and Filho et al., 2007; Babarinde and Adeyemo, 2010; Stejskal et al., 2014). Besides being known as a secondary pest of cereals, it has also been reported as a pest of plantain chips and yam flour (Babarinde et al., 2010; 2013). Our recent observation in the laboratory confirms the emergence of certain *T. castaneum* strain with the ability to infest and damage intact seeds of groundnut. It is also a pest of decorticated melon seeds. The species has assumed an economic importance because infested products contain insect fragment, benzoquinones and exuviae in addition to individuals of each life stage, which renders the products less attractive to their consumers. With the new observation of *T. castaneum*'s pest status, the necessity for its control becomes more apparent. Being polyphagous and cosmopolitan, a number of synthetic insecticides have been used for successful control of the insect pest (Islam and Talukdar, 2005; Iram et al., 2013). However, some chemicals have become ineffective against the pest due to the emergence of strains that have developed resistance against the chemicals (Guedes et al., 1996; Bajracharya et al., 2016). Moreover, synthetic chemicals like organophosphates, carbamate and organochlorine have numerous negative effects on human health and non-target beneficial organisms (Islam et al., 2011). In addition, many resource-poor local farmers find the cost of chemical control of pests to be highly unaffordable.

There is therefore the need to search for biorational methods for insect pest control in postharvest crop handling. Many indigenous plants have been used for protection of stored produce against *T. castaneum* in various countries with

marked levels of efficacy (Dales, 1996; Imtiaz et al., 1999; Babarinde and Ogunkeyede, 2008; Babarinde and Adeyemo, 2010; Popović et al., 2013; Dukić et al., 2016). *P. guineense* has established pesticidal potentials against major noxious insect pests of arable crops (Babarinde et al., 2011; Ntonifor, 2011). The toxicity of *Aframomum melegueta* against the khapra beetle, *Trogoderma granarium* Everts infesting groundnut and its repellence against the maize weevil, *Sitophilus zeamais* have been reported (Babarine and Daramola, 2006; Ukeh et al., 2009). Also, several bioactivities of *Eugenia aromatica* against insect pests have been reported (Adedire et al., 2005; Ofuya et al., 2010; Oyeniyi et al., 2015). Spinosad is an insect killer that was discovered from soil in an abandoned rum distillery in 1982, produced by fermentation. It is a fast-action commercial insecticide which can be used on outdoor ornamentals, vegetables and fruit trees, to control a broad spectrum of insects (Tescari et al., 2014; Bacci et al., 2016). Spinosad is effective against a broad range of stored product insects (Vayias et al., 2009; Athanassiou et al., 2010; Hertlein et al., 2011; Subramanyam et al., 2012; Andrić et al., 2013; Kemabonta et al., 2013).

Plant products are known to have negligible effects on beneficial insects and lower environmental impacts. They are easily affordable, available and play a useful role in Integrated Pest Management (IPM) programs in developing countries. Since most developing nations suffer from the high cost of synthetic pesticides, botanical products with modest efficacy are preferred if they are readily available and less expensive than the conventional pesticides. The production of plant powders requires no skills and knowledge and their use incurs low financial expenditure. Despite the numerous advantages of the botanical powder as a grain protectant, its major shortcoming is that it loses its efficacy sooner after application than the synthetic pesticides. This subsequently affects the effectiveness of botanicals as the pest control formulation (Babarinde et al., 2008a). Secondly, despite many reported high spinosad efficacies, the cost of its sole application may be unaffordable to postharvest crop handlers and resource-poor farmers in the developing countries. Therefore, this research was designed with the following objectives: (i) to assess the synergistic effect of spinosad on the bioactivity of selected botanical powders as protectants of stored decorticated melon seeds against *Tribolium castaneum* and (ii) to evaluate the phytochemical constituents of the studied botanicals.

Materials and Methods

Experimental site

The experiment was carried out at the Crop and Environmental Protection (CEP) Departmental Laboratory, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria.

Insect culture and experimental conditions

T. castaneum used for the study was collected from the colony originating from old poultry feed and maintained in the CEP Departmental Laboratory, LAUTECH, Ogbomoso. The emerged adults were sub-cultured in the laboratory, and the sub-culture was maintained on wheat flour in Kilner jars in the laboratory at ambient temperature (26 ± 3°C) and relative humidity (65 ± 5%) until new insects emerged using an earlier described method (Babarinde and Adeyemo, 2010). Bioassays were carried out under the same conditions.

Procurement and handling of experimental materials

Pesticide-free melon seeds were obtained from Wazo Market, Ogbomoso. The initial moisture content of the seeds was 3.25%. The melon seeds were sorted to ensure that only whole, intact and uninfested seeds were used. Dried fruits of *A. melegueta*, *E. aromatica* and *P. guineense* were purchased from local herb sellers at Jagun Market, Ogbomoso, Nigeria. Exogenous materials were removed, thereafter, the dried fruits were ground using an electric laboratory hammer mill. The finely ground powder was kept in a separate air tight plastic container and placed in a wooden cupboard in the laboratory until use. Spinosad manufactured by Dow Agroscience LLC was obtained from Saro Agrosciences Ltd in Lagos, Nigeria. It was well packed and sealed in a polythene bag at purchase and so kept until use.

Evaluation of the synergistic effect of spinosad with botanicals against *Tribolium castaneum*

Eight (8) treatments were prepared and separately added to 10 g of melon seeds. The corresponding values in gram of the insecticidal product (or mixture) per kilogram of melon seeds (g/kg) are shown in Table 1.

Twenty *T. castaneum* adults, one- to five-day-old, were introduced into each treatment. The experiment was set up in three replicates. Mortality data were recorded at 1, 3, 5, 7 and 14 days after treatment (DAT) and expressed as a percentage of the total number of introduced insects as follows:

$$PM = \left(\frac{NDI}{TNI}\right) X\ 100 \quad (1)$$

where PM = Percentage mortality; NDI = Number of dead insects; TNI = Total number of introduced insects.

Table 1. Applied treatments and their corresponding values in g/kg.

Treatment code	Applied doses to 10 g of melon seed	Corresponding values (g/kg)
Treatment A	500 mg of *Piper guineense* powder	50 g/kg
Treatment B	500 mg of *Eugenia aromatica* powder	50 g/kg
Treatment C	500 mg of *Aframomum melegueta* powder	50 g/kg
Treatment D	5 mg of spinosad + 250 mg of *Piper guineense* powder	0.5 g/kg + 25 g/kg
Treatment E	5 mg of spinosad + 250 mg of *Eugenia aromatica* powder	0.5 g/kg + 25 g/kg
Treatment F	5 mg of spinosad + 250 mg of *Aframomum melegueta* powder	0.5 g/kg + 25 g/kg
Treatment G	10 mg spinosad (SASp)	1 g/kg
Treatment H	Untreated control	-

Five weeks after treatment, data were taken on weights of treated melon seeds. Weight loss rate in % (PWL) was estimated as:

$$WL = OW - FW \quad (2)$$

$$PWL = (WL/OW)X100 \quad (3)$$

where WL = Weight loss; OW = Original weight; FW = Final weight; PWL = Percentage weight loss.

Quantitative phytochemical analysis of the studied botanicals

Phytochemical analysis of each botanical powder to quantify the contents of alkaloids, flavonoids, saponins, terpenoids, tannins, phenolics, steroids, and cardiac glycosides was done according to the standard method (Marcano and Hasenawa, 1991).

Experimental design and data analysis

The experiment was laid out in a completely randomized design, replicated three times. Data were subjected to analysis of variance and significant treatment means were separated using SNK at the 5% probability level.

Results and Discussion

Effects of botanical powders and spinosad on *Tribolium castaneum* adults and weight loss rate of melon seeds

There was no mortality in the untreated melon seeds (control). At 1 DAT, 13.33% PM observed in sole application of *E. aromatica* powder was significantly ($p<0.05$) higher than 1.67% and 0.00% observed in spinosad only (SASp) and sole

application of other botanical powders, respectively. It was observed that sole application of each botanical powder caused a lower level of PM than the PM observed when the botanical was combined with spinosad (Table 2).

Table 2. Mortality rate (%) of *Tribolium castaneum* adults exposed to spinosad-botanical powder mixtures.

Code	Treatment	Mortality rate (%)				
		1 DAT	3 DAT	5 DAT	7 DAT	14 DAT
A	*Piper guineense* powder	0.00±0.00^{a}	3.33±3.33^{a}	51.67±6.01^{b}	81.67±6.01^{c}	95.00±5.00^{c}
B	*Eugenia aromatica* powder	13.33±6.01^{b}	48.33±4.41^{b}	75.00±7.64^{c}	96.67±3.33^{d}	100.00±0.00^{c}
C	*Aframomum melegueta* powder	0.00±0.00^{a}	1.67±1.67^{a}	3.33±1,67^{a}	10.00±2.89^{b}	11.67±4.41^{b}
D	*Piper guineense* powder + spinosad	5.00±2.89^{ab}	85.00±7.64^{c}	100.00±0.00^{d}	100.00±0.00^{d}	100.00±0.00^{c}
E	*Eugenia aromatica* powder + spinosad	8.33±1.67^{ab}	86.67±1.67^{c}	95.00±2.89^{d}	100.00±0.00^{d}	100.00±0.00^{c}
F	*Aframomum melegueta* powder + spinosad	3.33±1.67^{ab}	8.33±1.67^{a}	60.00±10.41^{bc}	95.00±5.00^{d}	100.00±0.00^{c}
G	Spinosad only	1.67±1.67^{a}	90.00±5.00^{c}	100.00±0.00^{d}	100.00±0.00^{d}	100.00±0.00^{c}
H	Control	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.00^{a}
	ANOVA	df=7.23 F=3.481 P<0.05	df=7.23 F=113.961 P<0.05	df=7.23 F=61.594 P<0.05	df=7.23 F=178.818 P<0.05	df=7.23 F=338.286 P<0.05

DAT: Days after treatment; means (±) standard error; means along the columns with the same letter are not significantly different using the SNK test at the 5% probability level.

At 3–14 DAT, SASp caused significantly ($p<0.05$) higher PM than what was observed in sole application of *A. melegueta* powder. However, at 3–14 DAT, PM observed in melon seeds treated with SASp (90.00–100.00%) was not significantly different from PM observed in melon seeds treated with spinosad + *E. aromatica* powder (86.67–100.00%) and *P. guineense* powder mixtures (85.00–100.00%). Furthermore, at 3–5 DAT, a combination of spinosad with any of the botanical powders caused significantly higher mortality than sole application of the respective botanical powder. A similar trend was observed at 7–14 DAT for the combination of *P. guineense* or *A. melegueta* with spinosad (Table 2). The result indicates that spinosad synergistically improved the toxicity of *E. aromatica* powder at 3–5 DAT, *P. guineense* powder at 3–7 DAT and *A. melegueta* powder at 3–14 DAT against *T. castaneum*. Weight loss rate (PWL) was significantly ($p<0.05$) lower in untreated melon seeds (2.67%) and seeds treated with sole application of *A. melegueta* powder (3.28%) than the value observed in melon seeds treated with SASp (0.42%) and *E. aromatica* powder (0.71%). However, PWL observed in melon seeds treated with spinosad + botanical powder mixtures

(1.17–1.40%) was not significantly ($p>0.05$) different from PWL observed in seeds treated with SASp (0.42%) (Figure 1). This implies that spinosad exerted a synergistic effect in combination with *A. melegueta* in the prevention of weight loss due to feeding by *T. castaneum.*

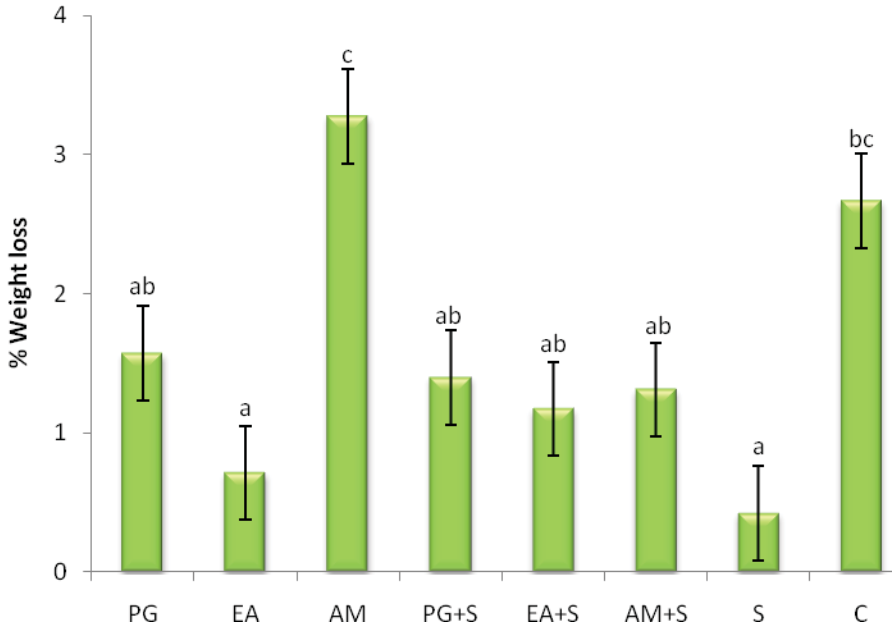

Figure 1. Weight loss rate (%) of melon seeds protected with mixtures of spinosad botanical powder due to infestation of *Tribolium castaneum* adults.

{*Piper guineense* (PG), *Eugenia aromatica* (EA), *Aframomum melegueta* (AM), *Piper guineense* + spinosad (PG+S), *Eugenia aromatica* + spinosad (EA+S), *Aframomum melegueta* + spinosad (AM+S), spinosad only (S), and untreated control (C). Means with the same letter are not significantly different using the SNK test at the 5% probability level}.

Regarding the PM data, it was observed that SASp and a mixture of spinosad with any of the 3 botanical powders showed higher efficacy in controlling *T. castaneum* infesting melon seeds compared to sole application of *A. melegueta* powder. However, all treatments caused significant PM when compared with the untreated control, where there was no mortality. At 14 DPT, 100% mortality was discovered in all treatments except that of sole application of *A. melegueta* powder. It implies that the mortality of *T. castaneum* in all spinosad botanical powder mixtures and sole application of spinosad progressed with the exposure period. A similar observation was made by Andrić et al. (2013), who evaluated the efficacy of spinosad and abamectin against different populations of *T. castaneum* infesting wheat grains. The treatments that exerted higher toxicity against *T. castaneum* also

gave better protection of melon seeds. This implies that the studied botanical insecticides had either or both adult toxicity and antifeedant effects against *T. castaneum.* PWL can be reduced when the insect population infesting the produce dies before they feed on the produce due to the toxicant present in the applied treatment. Adult mortality and antifeedant effects of botanical insecticides have been identified as noticeable mechanisms of botanical product action against insect pests (Bashir and El Shafie, 2013; Babarinde et al., 2014). Several authors have reported the modes of action of a powder formulation that kills the target arthropod. For instance, abrasion of the cuticle which consequently causes desiccation has been reported by Awam et al. (2012). Blockage of the spiracles by the dust particles has also been reported by EPA (1997).

The results on the potentials of SASp to cause adult mortality and prevent melon seed damage agree with earlier studies which reported the pesticidal potentials of spinosad against some stored product insect pests (Subramanyam et al., 2012; Nadeem et al., 2013). However, few other studies have indicated that the members of the genus *Tribolium* were least susceptible to spinosad when compared with other stored product insects (Subramanyam et al., 1999; Vayias et al., 2009). Spinosad has a low level of toxicity on non-target predatory insects. The insect pest that ingests spinosad dies within about 2 days after ingesting the active ingredient. It is eco-friendly and does not persist in the environment.

Phytochemical analysis of the studied botanical products

Table 3 shows the secondary metabolites present in the studied botanical powders. *P. guineense* powder had a significantly ($p<0.05$) higher level of alkaloids (868.33 mg/100 g) than 771.67 and 543.33 mg/100 g present in *A. melegueta* powder and *E. aromatica* powder, respectively. Similarly, the levels of tannins (550.00 mg/100 g), phenolics (53.57 GAE/g) and steroids (740.00 mg/100 g) were significantly higher in *P. guineense* powder than the levels present in the other two botanical powders. The levels of terpenoids (1276.67 mg/100 g) and cardiac glycosides (7.33 mg/100 g) were significantly higher in *E. aromatica* powder than the levels present in the other two botanicals, whereas *A. melegueta* powder had significantly higher levels of saponins (376.67 mg/100 g) than the other two botanical powders.

Regarding the results of the phytochemical analysis of the studied botanicals, higher quantities of some secondary metabolites were found in *P. guineense* and *E. aromatica* powders than the level present in *A. melegueta* powder. For instance, the levels of alkaloids, tannins, phenols and steroids were higher in *P. guineense* powder; the levels of flavonoids and terpenoids were higher in *E. aromatica* powder, while *A. melegueta* powder had only saponins as the predominant secondary metabolites. The array of phytochemicals found in the studied botanical powder was similar to those found in those botanical products/powders elsewhere

by previous authors (Echo et al., 2012; Kadam et al., 2015). In earlier studies, the quality and quantity of phytochemicals present in botanical insecticide products were reported to be contributory to their inherent toxicity against arthropods. For instance, Rattan (2010) listed alkaloids, terpenoids and phenolics as insecticidal secondary metabolites present in many insecticidal plants.

Table 3. Phytochemical contents of the studied botanical powders.

Botanicals	Alkaloids (mg/100 g)	Flavonoids (mg/100 g)	Saponins (mg/100 g)	Terpenoids (mg/100 g)	Tannins (mg/100 g)	Phenolics (GAE/g)	Steroids (mg/100 g)	Cardiac glycosides (mg/100 g)
Piper guineense powder	868.33± 14.81^{c}	1065.00± 14.43^{b}	316.67± 7.26^{b}	755.00± 14.43^{a}	550.00± 7.64^{c}	53.57± 0.15^{c}	740.00± 8.66^{c}	5.33± 0.17^{b}
Eugenia aromatica powder	543.33± 11.67^{a}	1466.67± 13.02^{c}	266.67± 11.67^{a}	1276.67± 11.67^{c}	363.33± 7.26^{a}	45.37± 0.20^{a}	235.00± 8.66^{a}	7.33± 0.73^{c}
Aframomum melegueta powder	771.67± 10.93^{b}	930.00± 5.00^{a}	376.67± 7.26^{c}	830.00± 8.66^{b}	425.00± 8.66^{b}	48.57± 0.18^{b}	441.67± 11.67^{b}	2.83± 0.44^{a}
ANOVA	df=2.8 F=175.901 p<0.05	df=2.8 F=580.434 p<0.05	df=2.8 F=37.655 p<0.05	df=2.8 F=568.934 p<0.05	df=2.8 F=145.806 p<0.05	df=2.8 F=549 p<0.05	df=2.8 F=675.854 p<0.05	df=2.8 F=20.333 p<0.05

Means along the columns with the same letter are not significantly different using the SNK test at the 5% probability level.

Although the abundance of the secondary metabolites was not correlated with PM, the comparatively low level of *A. melegueta* efficacy could be due to its comparatively reduced number of the predominant secondary metabolites. Spinosad is non-persistent in the environment and can be broken down by sunlight to harmless carbon, hydrogen, oxygen and nitrogen (Saunders and Bret, 1997; Akbar et al., 2010). Hence, it is ecologically safer than some other synthetic pesticides used for protection of stored products.

Conclusion

Among the three botanical insecticides studied in this research, *P. guineense* and *E. aromatica* powders showed greater insecticidal potential than *A. melegueta* powder. A synergistic effect of spinosad was observed when combined with *P. guineense* and *E. aromatica* powders in causing the death of *T. castaneum* at 3–7 DAT. Spinosad also improved the toxicity of *A. melegueta* against *T. castaneum* and the ability of the botanical powder to reduce melon weight loss due to the infestation of *T. castaneum.* The results of this study show spinosad as a synergist for the botanical powders and establish its relevance in stored product protection. These botanicals are used in human medicine or as condiments for food and drinks

in Africa. This fact presumes their relative safety for human consumption. The dose of spinosad used in this study (0.5 g /kg mixed with botanical powders) is safe for the environment, with low toxicity against non-target organisms. Although all the botanical powders showed better ability to control *T. castaneum* when combined with spinosad than their respective sole applications, *P. guineense* and *E. aromatica* performed better than *A. melegueta.* Therefore, combination of spinosad with either *P. guineense* or *E. aromatica* powder can be an effective biorational formulation for the protection of stored melon seeds from *T. castaneum.*

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SINERGISTIČKI EFEKAT SPINOSADA I ODABRANIH BOTANIČKIH PREPARATA KAO BIORACIONALNIH INSEKTICIDA U SUZBIJANJU ODRASLIH JEDINKI *TRIBOLIUM CASTANEUM* HERBST, 1797 (COLEOPTERA: TENEBRIONIDAE)

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R e z i m e

Ispitivan je sinergistički efekat kombinacije spinosada i tri botanička preparata dobijenih od biljaka: *Aframomum melegueta, Eugenia aromatica* i *Piper guineense* kao bioracionalnih insekticida u suzbijanju kestenjastog brašnara, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae), koji napada seme lubenice (*Citrullus lanatus*). Tretmani su podrazumevali samostalnu primenu svakog botaničkog preparata (50 g/kg semena lubenice), samostalnu primenu spinosada (1,0 g/kg), smešu spinosad (0,5 g/kg) + botanički preparati (25 g/kg) i netretiranu kontrolu. Prikupljeni su podaci o stepenu mortaliteta *T. castaneum* (%) i stepenu gubitka mase semena lubenice izraženog u %. Izvršena je takođe fitohemijska analiza botaničkih preparata. U ocenama 3−14 dana posle tretiranja (DPT), stepen mortaliteta jedinki utvrđen na semenu lubenice, koje je tretirano spinosadom (90,00−100,00%) nije se značajno ($p>0,05$) razlikovao od stepena mortaliteta jedinki koji je zabeležen na semenu koje je tretirano smešom spinosad + ekstrakt biljke *E. aromatica* (86,67−100,00%) i smešom spinosad + ekstrakt biljke *P. guineense* (85,00−100,00%). Stepen gubitka mase semena koji je utvrđen na semenu lubenice koje je tretirano kombinacijom spinosad + botanički preparati (1,17−1,40%) nije se značajno razlikovao od vrednosti zabeleženih na semenu koje je tretirano samo sa spinosadom (0,42%), ali je, sa druge strane, stepen gubitka mase semena bio značajno niži u poređenju sa vrednostima utvrđenim za seme koje je tretirano samo ekstraktom *A. melegueta* (3,28%). Ekstrakt *P. guineense* imao je najviši sadržaj alkaloida (868,33 mg/100 g), tanina (550,00 mg/100 g), fenola (53,57 GAE/g), i steroida (740,00 mg/100 g). Ekstrakt *E. aromatica* imao je najviši sadržaj flavonoida (1466,67 mg/100 g), terpenoida (1276,00 mg/100 g) i glikozida (7,33 mg/100 g), dok je ekstrakt *A. melegueta* imao najviši sadržaj saponina (376,67 mg/100 g). Kombinacija spinosada i ekstrakta *P. guineense* ili *E. aromatica* se pokazala efikasnijom nego kombinacija spinosada i ekstrakta *A. melegueta*, te se stoga može preporučiti kao bioracionalna mera za suzbijanje kestenjastog brašnara, *T. castaneum.*

Ključne reči: kestenjasti brašnar, spinosad, seme, sinergistički efekat, lubenica, botanički preparat.

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EFFECTS OF APPLE AND ORANGE JUICES ON QUALITY OF REFRIGERATED GOAT SEMEN

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Abstract: This study investigated the effects of apple and orange juices on quality of refrigerated spermatozoa of goat bucks. Semen samples from WAD goat bucks were diluted with Tris-egg yolk extenders each supplemented with apple and orange juices at 0, 2.5, 5, 7.5 and 10/100 ml of diluents. The diluted semen samples were assessed for sperm viability and malondialdehyde (MDA) concentration after *in vitro* storage for 240 hours at 5^{o}C. The ability to maintain sperm motility was higher in the extenders with 7.5% orange juice followed by 10% apple juice compared to other treatments ($P<0.05$). The extenders supplemented with 2.5%, 5% and 7.5% apple juice, and 5% orange juice had higher intact acrosome compared to other treatments and the control ($P<0.05$). The 10% orange juice had higher percentage membrane integrity compared to other treatments. Consistent and reduced ($P<0.05$) MDA levels were observed in the extenders supplemented with fruit juices and lower MDA was observed in the extenders supplemented with 10% apple juice compared to other treatments and the control ($P<0.05$). The findings reveal that additions of the fruit juices to semen extenders to maintain the viability of refrigerated spermatozoa were best at concentrations of 10 ml/100 ml of apple juice and 7.5 ml/100 ml of orange juice.

Key words: antioxidants, bucks, fruit juice, liquid storage, sperm viability.

Introduction

Goat is the most numerous domestic livestock species in Nigeria and presents a great potential to alleviate the problem of protein malnutrition (FAO, 2006). As the demand for these animals is constantly increasing, key steps in rapid multiplication of these animals will be important tools to reduce malnutrition. The genetic improvement of goats requires the selection of superior breeding stock and

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the application of an artificial insemination technique. The prospect of artificial insemination in goats generally varies with methods of semen preservation and insemination (Sugulle et al., 2006). In Nigeria, a lack of a reliable method for short-term storage of semen is a limiting factor. Short-term storage with diluents adequate in nutrients for the spermatozoa and a buffer against changes in pH as well as reduced oxygen environment provide a simple means for storage of buck semen. However, during storage, a decline in some semen quality indices such as motility, functional integrity and fertilizing capability of the sperm is a major problem encountered (Vishwanath and Shannon, 2000). One major factor contributing to poor quality semen is seminal oxidative stress caused by lipid peroxidation (Henkel, 2011). Small ruminants usually have a higher concentration of polyunsaturated fatty acids in the sperm membrane compared to other species rendering the sperm susceptible to oxidative stress damage (Henkel, 2011). Sperm cells generally have antioxidants as a defense mechanism against the attack of reactive oxygen species, however, this defense system is inadequate (Saleh et al., 2002). The semen extender supplemented with antioxidants may reduce this effect of reactive oxygen species caused by lipid peroxidation. The addition of antioxidants to the extender has been shown to improve sperm viability of bovine semen (Krzyzosiak et al., 2000; Bilodeau et al., 2002). Vitamins A, C and E have been shown to be potent antioxidants (Breininger et al., 2005; Ondei et al., 2009). The inclusion of fruit juices from orange (*Citrus sinensis*), cucumber (*Cucumis sativus*) and pineapple (*Ananas comosus*) as constituents of semen extenders has recently been proved to improve the quality of stored spermatozoa (Daramola et al., 2016). Apple (*Malus domestica)* and orange (*Citrus sinensis*) are antioxidant-rich fruits with high levels of these vitamins (Cutler et al., 2008) that probably outweigh other food nutrients in reducing the effect damage by reactive oxygen species. Information on the effects of apple and orange juices in extenders on sperm preservation during refrigeration has not been obtained. The aim of this experiment therefore was to assess the effects of juices of these antioxidant-rich fruits on the quality of refrigerated semen of WAD goat bucks.

Materials and Methods

Location of the experiment and management of animals

The Goat Unit of University Farm, Federal University of Agriculture, Abeokuta, located in the south-west of Nigeria was used for the experiment. Six intact West African Dwarf goat bucks and one matured teaser doe were used for the experiment. The bucks ranged between 4 and 5 years with an average weight of 18kg. The animals were managed intensively and fed with concentrate feed and guinea grass (*Panicum maximum*).

Juice preparation

The procedure of Adeyemo et al. (2007) with some modifications was used to prepare the fruit juice. Washed fresh fruits of apple and orange were first peeled (orange), cut into pieces, seeds removed and thereafter blended for five minutes. The blended fruits were sieved and pressure was applied manually to squeeze the juice from the blended fruits. The juices collected were centrifuged (3000 rpm) for 20 minutes and the supernatant fluid obtained was decanted into a clean beaker and used fresh with a tris-based extender.

Semen collection, dilution and refrigeration

Semen samples collected using an artificial vagina from six WAD goat bucks were pooled and diluted with a Tris-egg yolk based extender consisting of tris-hydroxymethyl-aminomethane (2.42g), citric acid (1.36g), glucose (1g), penicillin (0.028g), egg yolk (20 ml) and distilled water made up 100 ml as the control. Prior to dilution with the semen sample, the extender was supplemented each with apple and orange juice at 2.5, 5.0, 7.5 and 10/100 ml of the diluents respectively. Following dilution, the semen was dispensed into 5 ml tubes, sealed and chilled at 5°C for 240 hours in a refrigerator. The pH of the fruit-juice extenders with the aid of a digital pH meter was determined as follows: control: 7.03, apple juice extender: 7.14 and orange juice extender: 6.98.

Semen evaluation

Sperm motility

Following the procedure described by Bearden and Fuquay (1997), semen samples were kept warmed at 37°C for 3 minutes and accessed for sperm progressive motility by three observers using a Celestron Penta View LCD digital microscope (400x magnification) with a warmed slide (37°C). Motility assessment was carried out at an interval of 24 hours for 240 hours. Estimations were performed for the pooled semen samples in repeated observations using five different slides for each treatment. Sperm abnormality was evaluated with the use of eosin-nigrosin smears under a Celestron Penta View LCD digital microscope (400x magnification) for percentage of defects in the head, mid-piece and tail as described by Bearden and Fuquay (1997).

Acrosome and membrane integrities

Assessment of acrosome integrity was carried out in a formalin citrate solution (96 ml 2.9% sodium citrate and 4 ml 37% formaldehyde) as earlier described

(Ahmad et al., 2003) to identify the acrosome that showed a normal apical ridge of sperm cells using a Celestron Penta View LCD digital microscope (400x magnification). Fructose (9 g) plus sodium citrate (4.9 g) mixed with 1000 ml of distilled water was used as a hypo-osmotic swelling test to assess the membrane integrity of the sperm cells as described by Zubair et al. (2013). This is used to observe swelled spermatozoa that showed a coiled tail as against those with the intact plasma membrane under a Celestron Penta View LCD digital microscope (400x magnification).

Malondialdehyde

At the end of every 24 hours, a thiobarbituric acid reactive substance was used to assess the concentration of malondialdehyde (MDA) in the preserved semen as described by Pipan et al. (2014).

Statistical analysis

Data obtained were subjected to a 2 x 5 x 11 factorial arrangement, using SPSS version 16 and significantly different means were separated by Duncan's multiple range test (Duncan, 1955). The model used is provided below:

$$Y_{ijkl} = \mu + A_i + L_j + T_k + (AL)_{ij} + (AT)_{ik} + (LT)_{jk} + (ALT)_{ijk} + \sum_{ijkl,} \quad (1)$$

where,

Y_{ijkl} = Dependent variables,

μ = Population mean,

A_i = Effect due to the i^{th} fruit juices, i = 1, 2,

L_j = Effect due to the j^{th} level of inclusion, j = 0, 2.5, 5, 7.5, 10,

T_k = Effect due to the k^{th} duration of storage, k = 0, 24, 48, 72, 96 …….240,

$(AL)_{ij}$ = Effect due to the ij^{th} interaction between fruit juices and levels of inclusion,

$(AT)_{ik}$ = Effect due to the ik^{th} interaction between fruit juices and refrigeration period,

$(LT)_{jk}$ = Effect due to the jk^{th} interaction between levels of inclusion and refrigeration period,

$(ALT)_{ijk}$ = Effects due to the ijk^{th} interaction between fruit juices, levels of inclusion and refrigeration period, and

$\sum_{ijkl}$ = Experimental error.

Results and Discussion

The effects of apple and orange juices on progressive spermatozoa motility of chilled spermatozoa of WAD goat bucks are presented in Table 1. The results indicate consistently higher ($P<0.05$) sperm motility in 7.5% and 10% apple juice and 7.5% orange extenders compared to the control group, except 7.5% apple juice

at 216 h of storage. The ability to maintain higher sperm motility was higher in the extenders supplemented with 7.5% orange juice compared to other extenders and the control group (P<0.05).

Table 1. Progressive motility (%) of refrigerated spermatozoa in Tris-egg yolk extenders supplemented with juices.

Duration (h)	Control	Apple (%)				Orange (%)				SEM
		2.5	5	7.5	10	2.5	5	7.5	10	
n	5	5	5	5	5	5	5	5	5	
0	94.00^{a}	82.00^{bc}	98.00^{a}	86.00^{b}	88.00^{b}	76.00^{d}	98.00^{a}	88.00^{b}	96.00^{a}	4.081
24	74.00^{bc}	80.00^{a}	64.00^{d}	82.00^{a}	72.00^{c}	70.00^{c}	78.00^{b}	82.00^{a}	84.00^{a}	4.727
48	62.00^{d}	66.00^{bc}	58.00^{e}	70.00^{b}	68.00^{b}	66.00^{bc}	58.00^{f}	78.00^{a}	58.00^{e}	4.402
72	54.00^{d}	58.00^{c}	58.00^{c}	66.00^{b}	66.00^{b}	64.00^{b}	54.00^{d}	74.00^{a}	58.00^{c}	4.271
96	54.00^{d}	56.00^{bc}	50.00^{ed}	58.00^{b}	62.00^{ab}	52.00^{d}	50.00^{ed}	64.00^{a}	52.00^{d}	4.943
120	54.00^{b}	50.00^{b}	48.00^{c}	62.00^{a}	62.00^{a}	46.00^{c}	42.00^{d}	62.00^{a}	46.00^{c}	5.250
144	52.00^{c}	48.00^{c}	44.00^{d}	58.00^{b}	62.00^{a}	26.00^{f}	30.00^{f}	62.00^{a}	40.00^{e}	5.015
168	42.00^{b}	42.00^{b}	20.00^{e}	40.00^{bc}	60.00^{a}	28.00^{e}	24.00^{e}	60.00^{a}	32.00^{de}	5.505
192	40.00^{cd}	42.00^{c}	16.00^{f}	40.00^{cd}	54.00^{b}	26.00^{e}	22.00^{e}	58.00^{a}	26.00^{e}	5.271
216	40.00^{c}	12.00^{e}	6.00^{f}	30.00^{d}	44.00^{b}	10.00^{e}	14.00^{e}	52.00^{a}	10.00^{e}	5.690
240	16.00^{de}	10.00^{e}	8.00^{e}	20.00^{bc}	26.00^{b}	0.00^{f}	8.00^{e}	34.00^{a}	10.00^{e}	4.872

$^{a, b, c, d, e, f}$ Values within a row with different superscripts differ significantly (P<0.05).

Table 2. Acrosome integrity (%) of refrigerated spermatozoa in Tris-egg yolk extenders supplemented with juices.

Duration (h)	Control	Apple (%)				Orange (%)				SEM
		2.5	5	7.5	10	2.5	5	7.5	10	
n	5	5	5	5	5	5	5	5	5	
0	94.50^{b}	97.00^{a}	98.00^{a}	97.50^{a}	98.50^{a}	95.50^{ab}	94.00^{b}	98.00^{a}	96.50^{ab}	1.390
24	92.50^{a}	90.50^{ab}	90.00^{ab}	92.00^{a}	89.50^{b}	90.00^{ab}	90.50^{ab}	93.50^{a}	91.00^{ab}	1.095
48	86.00^{a}	77.50^{c}	84.00^{a}	83.50^{a}	85.00^{a}	85.00^{a}	82.00^{ab}	86.50^{a}	80.50^{b}	2.525
72	76.00^{b}	72.00^{c}	78.50^{a}	76.00^{b}	76.50^{b}	76.00^{b}	76.00^{b}	80.50^{a}	74.50^{bc}	1.878
96	73.00^{bc}	69.50^{cd}	66.50^{d}	70.00^{c}	86.50^{a}	66.00^{d}	68.00^{d}	74.00^{b}	71.00^{c}	2.628
120	64.00^{b}	61.50^{c}	60.50^{c}	66.00^{a}	66.50^{a}	61.50^{c}	62.00^{c}	62.50^{c}	62.50^{c}	2.466
144	57.50^{b}	53.00^{d}	54.50^{c}	55.5^{bc}	59.50^{a}	55.00^{bc}	52.00^{d}	55.00^{bc}	56.00^{b}	2.568
168	52.00^{a}	47.00^{c}	46.00^{d}	49.00^{b}	49.50^{b}	47.50^{c}	46.50^{cd}	46.00^{d}	44.50^{d}	2.666
192	40.00^{c}	44.50^{a}	41.00^{b}	41.00^{b}	38.50^{c}	39.50^{c}	41.50^{b}	36.25^{d}	34.00^{e}	2.856
216	32.00^{d}	39.00^{a}	35.00^{b}	36.50^{b}	33.50^{bc}	33.50^{bc}	34.00^{bc}	32.50^{d}	30.00^{e}	2.090
240	28.00^{c}	35.00^{a}	30.25^{b}	32.00^{b}	27.00^{c}	28.50^{c}	30.00^{b}	27.50^{c}	25.50^{d}	2.150

$^{a, b, c, d, e}$ Values within rows with different superscripts differ significantly (P<0.05).

The effects of apple and orange juices on the intact acrosome of chilled spermatozoa of WAD goat bucks are presented in Table 2. The values obtained for the intact acrosome did not follow a particular pattern. However, higher values of the intact acrosome were obtained when the extender was supplemented with 7.5% orange juice at 24, 48, and 72 hours. Apple juice, however, improved the intact acrosome when the extender was supplemented with 10% at 96, 120, 144 and 168 hours. The extenders supplemented with the juices moreover had better intact acrosome after post-chilling at 240 hours of storage following the addition of 2.5%, 5% and 7.5% apple juice, and 5% orange juice compared to other treatments and the control ($P<0.05$).

The effects of apple and orange juices on the percentage membrane integrity of chilled spermatozoa of WAD goat bucks are presented in Table 3. Consistently higher values of percentage membrane integrity in 2.5% and 10% apple juice extenders during the 240 hours of storage were observed while consistently higher values of the percentage membrane integrity in the extender supplemented with all levels of orange juice except at 2.5% were observed after 48 up to 240 hours of storage compared to the control group.

Table 3. Membrane integrity (%) of refrigerated spermatozoa in Tris-egg yolk extenders supplemented with juices.

Duration (h)	Control	Apple (%)				Orange (%)				SEM
		2.5	5	7.5	10	2.5	5	7.5	10	
n	5	5	5	5	5	5	5	5	5	
0	92.00^{c}	96.00^{a}	94.50^{b}	97.50^{a}	94.50^{b}	94.00^{b}	95.00^{ab}	94.50^{b}	95.00^{ab}	1.270
24	80.00^{d}	86.00^{b}	80.50^{d}	89.50^{a}	83.00^{c}	78.50^{d}	79.00^{d}	77.00^{d}	80.50^{d}	4.283
48	71.00^{e}	79.50^{b}	72.00^{d}	72.50^{d}	81.00^{a}	69.50^{e}	73.50^{d}	74.50^{cd}	76.50^{c}	3.696
72	67.00^{e}	77.00^{a}	61.50^{f}	69.00^{d}	75.00^{ab}	62.50^{f}	70.50^{c}	71.50^{c}	73.00^{b}	4.186
96	61.00^{d}	66.50^{bc}	56.50^{e}	59.00^{d}	71.00^{a}	61.00^{d}	68.00^{b}	67.50^{b}	70.00^{a}	3.765
120	52.00^{e}	61.00^{d}	52.00^{e}	54.50^{e}	67.50^{a}	53.00^{e}	63.00^{c}	60.00^{d}	65.00^{b}	3.606
144	49.50^{d}	54.00^{c}	46.00^{de}	47.00^{de}	59.50^{a}	51.50^{c}	57.50^{ab}	53.50^{c}	60.00^{a}	2.920
168	44.00^{c}	48.50^{b}	40.00^{d}	44.00^{c}	52.50^{a}	45.00^{c}	53.50^{a}	42.00^{cd}	52.00^{a}	2.928
192	38.00^{e}	39.50^{d}	37.50^{e}	38.00^{e}	45.50^{b}	41.50^{c}	45.50^{b}	39.50^{d}	47.00^{a}	2.022
216	32.50^{d}	35.00^{c}	31.00^{d}	34.00^{c}	35.50^{c}	36.00^{c}	40.00^{a}	33.50^{cd}	38.50^{b}	1.788
240	27.50^{d}	30.50^{c}	26.50^{de}	30.50^{c}	33.00^{b}	33.00^{b}	36.50^{a}	30.50^{c}	33.50^{b}	1.907

$^{a, b, c, d, e, f}$ Values within rows with different superscripts differ significantly ($P<0.05$).

The effects of apple and orange juices on percentage abnormality of chilled spermatozoa of WAD goat bucks are presented in Table 4. The results show a consistently lower percentage abnormality in the extenders supplemented with 7.5% orange and 10% apple juices compared to other inclusion levels and the control group ($P<0.05$).

Table 4. Abnormality (%) of refrigerated spermatozoa in Tris-egg yolk extenders supplemented with juices.

Duration (h)	Control	Apple (%)				Orange (%)				SEM
		2.5	5	7.5	10	2.5	5	7.5	10	
n	5	5	5	5	5	5	5	5	5	
0	0.-0.30^{c}	0.83^{b}	0.00^{e}	0.43^{c}	0.33^{c}	1.00^{a}	0.15^{d}	0.30^{c}	0.15^{d}	1.940
24	1.-1.38^{b}	1.13^{b}	1.45^{a}	0.63^{c}	1.30^{b}	1.38^{b}	1.00^{b}	0.70^{c}	0.58^{c}	2.605
48	2.15^{a}	2.28^{a}	2.10^{a}	1.50^{b}	1.85^{b}	1.65^{b}	2.30^{a}	1.10^{c}	1.70^{b}	3.278
72	2.83^{a}	2.90^{a}	2.48^{a}	1.70^{c}	2.18^{b}	1.98^{bc}	2.85^{a}	1.43^{d}	2.00^{b}	3.305
96	3-3.20^{a}	3.30^{a}	3.13^{a}	2.10^{c}	2.25^{c}	2.95^{b}	2.80^{b}	1.73^{d}	4-2.48^{b}	2-2.833
120	3.40^{b}	4.00^{a}	3.25^{b}	2.75^{c}	2.90^{c}	3.40^{b}	3.33^{b}	2.53^{c}	2.88^{c}	3.183
144	3.63^{b}	4.50^{a}	3.33^{c}	3.18^{c}	3.28^{c}	4.90^{a}	4.85^{a}	2.88^{d}	3.60^{b}	3.913
168	4.-4.18^{d}	5.08^{b}	5.63^{a}	4.65^{c}	3.58^{e}	4.93^{c}	5.68^{a}	3.40^{e}	4.23^{d}	4.197
192	4.-4.98^{cd}	5.30^{c}	6.20^{a}	4.93^{cd}	4.30^{e}	5.63^{b}	6.30^{a}	3.68^{e}	4.88^{cd}	3.848
216	5.-5.05^{d}	7.65^{a}	7.40^{ab}	5.50^{c}	4.38^{e}	6.30^{c}	6.88^{b}	3.68^{e}	6.-6.65^{b}	5.-5.555
240	6.-6.93^{c}	8.08^{a}	7.90^{a}	6.80^{c}	6.13^{d}	7.65^{ab}	7.65^{ab}	5.50^{e}	7.18^{c}	4.982

$^{a, b, c, d, e}$ Values within rows with different superscripts differ significantly (P<0.05).

Generally, consistently lower (P<0.05) levels of MDA were recorded in the extenders supplemented with fruit juices compared to the control except at 10% at 48 and 192 hours (Table 5). The lower MDA was observed in the extenders supplemented with 10% apple juice compared to other treatments and the control (P<0.05).

Table 5. MDA (nmol/mL) levels of refrigerated spermatozoa in Tris-egg yolk extenders supplemented with juices.

Duration (h)	Control	Apple (%)				Orange (%)				SEM
		2.5	5	7.5	10	2.5	5	7.5	10	
n	5	5	5	5	5	5	5	5	5	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
24	0.-0.02^{c}	0.02^{c}	0.03^{b}	0.01^{d}	0.01^{d}	0.02^{c}	0.02^{c}	0.05^{a}	0.03^{b}	0.023
48	0.06^{a}	0.05^{b}	0.05^{b}	0.04^{c}	0.03^{d}	0.05^{b}	0.04^{c}	0.06^{a}	0.06^{a}	0.055
72	0.10^{a}	0.07^{c}	0.07^{c}	0.07^{c}	0.05^{e}	0.06^{d}	0.06^{d}	0.07^{c}	0.09^{b}	0.045
96	0.15^{a}	0.08^{d}	0.09^{c}	0.09^{c}	0.06^{e}	0.10^{b}	0.09^{c}	0.12^{b}	0.10^{b}	0.042
120	0.16^{a}	0.10^{b}	0.12^{b}	0.11^{b}	0.08^{c}	0.13^{b}	0.09^{c}	0.13^{b}	0.12^{b}	0.038
144	0.17^{a}	0.13^{cd}	0.14^{bc}	0.14^{c}	0.09^{e}	0.15^{b}	0.12^{d}	0.14^{bc}	0.14^{bc}	0.055
168	1.18^{a}	0.14^{d}	0.15^{cd}	0.16^{c}	0.12^{e}	0.16^{c}	0.13^{de}	0.17^{b}	0.15^{cd}	0.069
192	0.20^{a}	0.15^{d}	0.17^{c}	0.18^{bc}	0.14^{d}	0.18^{bc}	0.18^{bc}	0.19^{b}	0.20^{a}	0.058
216	0.24^{a}	0.17^{de}	0.20^{c}	0.19^{d}	0.17^{de}	0.22^{b}	0.20^{c}	0.20^{c}	0.22^{b}	0.041
240	0.25^{a}	0.19^{de}	0.23^{c}	0.21^{d}	0.22^{d}	0.26^{a}	0.24^{b}	0.22^{d}	0.24^{b}	0.054

$^{a, b, c, d, e}$ Values within rows with different superscripts differ significantly (P<0.05).

The improved sperm viability that accompanied supplementation of semen extenders with apple and orange juices in this experiment has revealed that the fruit juices have the ability to maintain motility and this might be on account of their excellent source of antioxidants such as vitamins C and E present in these fruits (Mermeistein, 1999; Djuric and Powell, 2001; Gebhardt and Thomas, 2002; Martin et al., 2002). The findings agree with Ball et al. (2001), Reza et al. (2011) and Adikwu and Deo (2013) that vitamin E or C additions in preserved semen improved sperm motility. Vitamins C and E as antioxidants are known to eliminate superoxide anions and singlet oxygen and protect lipoproteins from peroxidative damage (Michael et al., 2008; Swaran and Flora, 2009). The results of this experiment agree with the previous works which have revealed that vitamin C exerted an antioxidative effect during freezing and thawing of bovine sperm (Beconi et al., 1993; Mermeistein, 1999). This, however, contradicts Aurichet et al. (1997), who reported that the addition of ascorbic acid did not improve motility of cooled equine spermatozoa during the 96-h storage period. Besides the vitamin C content in the fruits, the antioxidant properties of phenolic compounds present in these fruits might also be implicated in the improved motility observed (Spanos and Wrolstad, 2004). The important phenolic compound in orange juice is ferulic acid (Augustin and Williams, 2000) that acts synergistically with other antioxidants to reduce an adverse effect of free radicals on the external and internal membranes of cells (Zuo et al., 2002). The vitamins and phenolic compounds present in the juices could therefore be linked with progressive motility observed at various inclusions of juices (Mullen et al., 2007; USDA, 2009). Moreover, in the present study, the level of fruit juices seemed to be optimal for maintaining buck sperm motility, as effects of apple and orange juices varied with the level of supplementation in the extenders; namely, at higher concentrations, sperm motility was maintained and better preserved in the extenders with the addition of 10% and 7.5% apple and orange juices respectively. The juices seemed to play the role of oxidants at low levels and of antioxidants at higher levels. Apple juice, however, surpassed orange juice as it maintained sperm motility better at the higher level of supplementation. Previous studies, however, have shown that a stimulating effect of vitamin E on oxidation is more pronounced at higher concentrations while vitamin C is known to be effective as an oxidant at low concentrations (Breininger et al., 2005; Mullen et al., 2007).

Worthy of note in this experiment is that the addition of fruit juices to Tris-egg yolk extenders did not only improved sperm motility, but also maintained acrosome integrity and membrane integrity. In addition, the fruit juice extenders also reduced both percentage abnormality and MDA concentration in the chilled semen. A beneficial effect of antioxidants on intact acrosome and membrane integrities in the extenders with the addition of the fruit juices during 240 hours of refrigeration compared to the control group could possibly be linked to

vitamin C and other antioxidants in these juices (Mermeistein, 1999; Spanos and Wrolstad, 2004). The results of the present experiment therefore indicate that the combined action of these vitamins and phenolic compounds in the juices improved sperm parameters in the extenders supplemented with the fruit juices. The findings have corroborated the previous findings that observed a beneficial effect of ferulic acid on sperm viability and reduced lipid peroxidative damage to sperm membranes (Zheng and Zhang, 1997). The antioxidant ability of ferulic acid is linked to its structural characteristics (Kheradmand and Babaei, 2006; Marimuthu et al., 2007). Moreover, it is the synergistic activity of vitamin C, vitamin E and other antioxidants that stimulate the protective effects against lipid peroxidation and preservation of cell membrane integrity (Donoghue and Wishart, 2000; Rahman, 2007).

The lower level of MDA recorded in the fruit juice extenders compared to the control could probably be on account of flavonoids and ferulic acid in these fruits. This study agrees with the findings of Zheng and Zhang (1997) that orange and apple juice constituents particularly vitamin C, flavonoids and ferulic acid suppressed a damaging effect of lipid peroxidation during liquid storage of rooster's semen. The reduction in MDA agrees with the previous reports (Aurich et al., 1997; Arabi and Seidaie, 2008) that vitamin C protected the sperm cells from endogenous oxidative DNA and membrane damages. Fruits generally are rich in flavonoids, ferulic acid and vitamin C, which makes apple and orange juices potentially good sources of antioxidants for semen preservation. Moreover, major activities of antioxidants in fruits are from phenolic compounds (Cao et al., 1997). Therefore, the present study suggests that phenolics could play a vital role in antioxidant properties in addition to other hydroxycinnamic derivatives such as dicaffeoylquinic and chlorogenic acids in the fruits (Zhang and Hamauzu, 2004). This information further indicates that all improvements in semen parameters when treated with the fruit juices were linked to flavonoids and ferulic acid found in the juices in addition to vitamin C; and they acted synergistically to protect sperm cells from lipid peroxidation during refrigeration. The results of the present study therefore support the Fenton reaction (O'Flaherty et al., 2003) that antioxidants influence the removal of hydrogen peroxide to produce hydroxyl radicals. This effect explains the improved motility, acrosome and membrane integrities, reduced abnormality and MDA concentration when apple and orange juices were added to the extenders.

Conclusion

The findings indicate that the additions of the fruit juices to semen extenders were the most suitable and best at 10 ml/100 ml and 7.5 ml/100 ml of apple juice and orange juice respectively in maintaining sperm motility of buck spermatozoa

during liquid storage. The present results indicate that the additions of apple and orange juices to semen extenders are suitable agents for preserving semen quality in cold storage for up to 240 hours.

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UTICAJI SOKOVA OD JABUKE I POMORANDŽE NA KVALITET RASHLAĐENE SPERME JARČEVA

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R e z i m e

Ovim istraživanjem se proučavaju uticaji sokova od jabuke i pomorandže na kvalitet rashlađenih spermatozoida jarčeva. Uzorci sperme zapadnoafričkih patuljastih (engl. *West African Dwarf* − WAD) jarčeva razređeni su tris-razređivačima na bazi žumanceta jajeta, pri čemu je svaki od njih dopunjen sokovima od jabuke i pomorandže u količinama 0, 2,5, 5, 7,5 i 10/100 ml razređivača. Procenjena je životna sposobnost sperme i koncentracija malondialdehida (MDA) uzoraka razređene sperme posle skladištenja *in vitro* tokom 240 sati na 5°C. Sposobnost da se održi pokretljivost spermatozoida bila je viša kod razređivača sa 7,5% sokom od pomorandže, a zatim je sledio razređivač sa 10% sokom od jabuke u poređenju sa drugim tretmanima ($P<0,05$). Razređivači u kojima je dodat 2,5%, 5% i 7,5% sok od jabuke, i 5% sok od pomorandže imali su viši netaknuti akrozom u poređenju sa drugim tretmanima i kontrolom ($P<0,05$). Višeprocentni integritet membrane uočen je pri dodavanju 10% soka od pomorandže u poređenju sa drugim tretmanima. Dosledni i smanjeni ($P<0,05$) nivoi MDA uočeni su kod razređivača dopunjenim voćnim sokovima, a niži nivoi MDA su zabeleženi u razređivačima dopunjenim 10% sokom od jabuke u poređenju sa drugim tretmanima i kontrolom ($P<0,05$). Rezultati pokazuju da su dodavanja voćnih sokova u razređivače sperme kako bi se održala životna sposobnost spermatozoida bila najbolja pri koncentracijama 10 ml/100 ml soka od jabuke i 7,5 ml/100 ml soka od pomorandže.

Ključne reči: antioksidansi, jarčevi, voćni sok, skladištenje tečnosti, životna sposobnost sperme.

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ANALIZA SEDAM INDIREKTNIH METODA ZA PRORAČUN REFERENTNE EVAPOTRANSPIRACIJE U KLIMATSKIM USLOVIMA SRBIJE

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Sažetak: Za izračunavanje potreba za vodom poljoprivrednih kultura neophodno je imati uvid u proces evapotranspiracije. Metoda Penman-Monteith (FAO56-PM), koja je od strane Međunarodne komisije za navodnjavanje i odvodnjavanje (engl. *Internatioanl Commission on Irrigation and Drainage* – ICID) i Organizacije za hranu i poljoprivredu Ujedinjenih nacija (engl. *Food and Agriculture Organisation* – FAO) predložena za proračun referentne evapotranspiracije (ETo), zahteva poznavanje više klimatskih parametara, koji često nisu dostupni. Zato su u ovom radu testirane metode za proračun ETo koje koriste manji broj podataka i upoređivane sa FAO56-PM. Izabrane su metode koje su najčešće korišćene kao zamena za FAO56-PM: Hargreaves, modifikovani Hargreaves, Copais, Turc, Priestley-Taylor, Makkink i Hamon. Proračun je rađen na dnevnom i prosečnom mesečnom nivou, za period 2010–2013. godine, na stanicama: Niš, Beograd, Novi Sad, Loznica, Valjevo, Zlatibor, Ćuprija i Kikinda. Poseban značaj dat je vegetacionom periodu tokom sušne godine, interesantnom sa aspekta primene navodnjavanja. Upoređivanje metoda rađeno je na osnovu statističke analize, pri čemu su korišćeni parametri: MXE, MAE, RMSD, ARMSD, WRMSD, b i R^2. Najbolje slaganje sa metodom FAO-PM na prosečnom mesečnom nivou, kao i u letnjem periodu 2012. godine, pokazale su metode Copais, Turc i Priestley-Taylor, pa se one mogu preporučiti kao zamena za metodu FAO56-PM, u našim klimatskim uslovima. Ukoliko se raspolaže samo podacima o temperaturi vazduha, rezultati dobijeni u ovom istraživanju pokazuju opravdanost upotrebe modifikovane metode Hargreaves za proračun ETo u toku vegetacionog perioda.

Ključne reči: referentna evapotranspiracija, FAO56-PM, Turc, Priestley-Taylor, Hargreaves, modifikovani Hargreaves, Copais, Hamon, humidna i subhumidna klima.

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Uvod

Sa aspekta navodnjavanja, proračun evapotranspiracije je glavni element pri projektovanju hidromodula sistema. Prilikom određivanja potreba biljaka za vodom, potrebno je prvo odrediti referentnu evapotranspiraciju. Organizacija za hranu i poljoprivredu Ujedinjenih nacija (engl. *Food and Agriculture Organization,* FAO) dala je definiciju referente evapotranspiracije: „Referentna evapotranspiracija je evapotranspiracija sa hipotetičke referentne kulture pretpostavljene visine 0,12 cm, stalnog površinskog otpora od 70 s m-1 i sa albedom od 0,23 koja je bliska evapotranspiraciji sa velike površine pokrivene zelenom travom u fenofazi aktivnog rasta i u uslovima bez nedostatka lakopristupačne vlage" (Allen et al., 1998).

Međunarodna komisija za navodnjavanje i odvodnjavanje (ICID) i Organizacija za hranu i poljoprivredu Ujedinjenih nacija (FAO) predlažu metodu Penman-Monteith (FAO56-PM) za proračun referentne evapotranspiracije.

Rezultati Lopez-Urrea et al. (2006), koji su upoređivali dnevne vrednosti evapotranspiracije dobijene direktnom metodom, merenjem lizimetrom, sa sedam indirektnih metoda za čiji su proračun korišćeni dnevni klimatski podaci, potvrđuju izbor metode FAO 56-PM kao referentne. U uslovima semiaridne klime, formula FAO 56-PM pokazala je nabolje slaganje sa dnevnim vrednostima ETo merenim pomoću lizimetra. Slede metode: Hargreaves, FAO-24 Radiation, FAO-24 Penman (II), FAO-24 Penman (I), Penman i FAO-24 Blaney-Criddle. Upoređivanje je rađeno u toku letnje (april−septembar) i zimske (oktobar−mart) sezone. U oba slučaja, metoda FAO-56 Penman-Monteith se pokazala kao najpreciznija.

Međutim, u slučaju nedostatka klimatskih podataka (insolacije, brzine vetra, relativne vlažnosti vazduha), primena metode FAO 56-PM za proračun evapotranspiracije je limitirana. Todorovic et al. (2013) su stoga upoređivali standardnu metodu FAO 56-PM sa metodom Hargreaves, poznatu pod nazivom temperaturna metoda FAO 56-PM, koja koristi samo podatke o temperaturi vazduha. Korišćeni su podaci sa 577 stanica iz oblasti mediteranske klime. U oblastima sa aridnom klimom, rezultati vrednosti kvadratnog korena srednje greške (engl. *root-mean-square error* − RMSE) za obe metode su u intervalu od 0,60 do 0,65 mm dan^{-1}. U vlažnim subhumidnim i humidnim oblastima metodom Hargreaves dobijene su značajno veće vrednosti u odnosu na metodu FAO 56-PM. Droogers i Allen (2002) su takođe analizirali podudarnost metode Hargreaves sa metodom FAO 56-PM. Koristili su tridesetogodišnje podatke sa 56.000 stanica. Zaključili su da je, u slučaju kada nedostaju klimatski podaci, opravdana zamena metode FAO 56-PM metodom Hargreaves, ali da se znatno bolji rezultati postižu primenom metode Hargreaves koju je izmenio Allen (2003). Metoda uključuje korišćenje mesečne sume padavina i izmenjen eksponent, sa 0,5 na 0,76 (RMSD 0,72 mm dan^{-1}). Slična istraživanja je sprovodio i Trajkovic (2005) i pokazao da se primenom metode Hargreaves dobijaju za u proseku 21% veće vrednosti nego

metodom FAO 56-PM. Nakon regionalne kalibracije, ta razlika je smanjena na 13%. Dobijeni rezultati su ukazali na to da regionalnu kalibraciju treba odraditi upotrebom izmenjenog Hargreaves eksponenta. Na osnovu ispitivanja podataka sa meteoroloških stanica iz Srbije, Trajković preporučuje vrednost eksponenta 0,424. Dobijena razlika u ovom slučaju, u odnosu na standradnu metodu FAO 56-PM je 0,3% (Trajković, 2007a).

S obzirom na to da metoda FAO 56-PM zahteva veliki broj klimatskih podataka koji često nisu dostupni, interesantno je, u okviru naših klimatskih uslova, ispitati metode koje za svoj obračun zahtevaju mali broj klimatskih podataka. Koristeći klimatske podatke sa agrometeorološke stanice Radmilovac, smeštene na eksperimentalnom polju Poljoprivrednog fakulteta Univerziteta u Beogradu, Alexandris et al. (2008) su testirali šest različitih metoda za proračun evapotranspiracije. Najbolje slaganje sa metodom FAO 56-PM pokazale su metode Priestly-Taylor (RMSE 0,195 mm·dan^{-1}) i Copais (RMSE 0,281 mm·dan^{-1}). Cilj ovog rada je da se na osnovu podataka sa više meteoroloških stanica širom Srbije testiraju različite metode indirektnog proračuna evapotranspiracije, poređenjem sa metodom FAO 56-PM. Poseban značaj se daje vegetacionom periodu tokom sušne godine, koji je interesantan sa pozicije primene navodnjavanja.

Materijal i metode

Proračun dnevne referentne evapotranspiracije, za četvorogodišnji period na teritoriji Srbije, vršen je sledećim metodama: Hargreaves, modifikovani Hargreaves, Copais, Turc, Priestley-Taylor, Makkink i Hamon. Dobijeni rezultati su upoređivani sa metodom Penman-Monteith (FAO56-PM), koja je predložena od strane Organizacije za hranu i poljoprivredu Ujedinjenih nacija (FAO) za proračun referentne evapotranspiracije (FAO56-PM).

Jednačina FAO56-PM glasi:

$$ETo = \frac{0{,}408 \cdot \Delta \cdot (Rn - G) + \gamma \cdot \frac{900}{Tm+273} \cdot u2 \cdot (es - ea)}{\Delta + \gamma \cdot (1 + 0{,}34 \cdot u2)} \quad (1)$$

gde je: ETo – referentna potencijalna evapotranspiracija (mm·dan^{-1}); Δ – nagib krive vodene pare (kPa·°C^{-1}); Rn – neto radijacija (MJ·m^{-2}·dan^{-1}); G – energija utrošena za zagrevanje zemljišta (MJ·m^{-2}·dan^{-1}); γ – psihrometarska konstanta (kPa·°C^{-1}); Tm – srednja temperatura vazduha (°C); u_2 – brzina vetra merena na 2 m visine (m/s); $(es - ea)$ – deficit napona vodene pare (kPa); es – srednji saturacioni napon vodene pare (kPa); ea – stvarni napon vodene pare (kPa).

Urađena je korekcija parametara Rs i Rso po formulama koje preporučuju Allen et al. (1998) i Perera et al. (2015). Solarna radijacija vedrog neba je računata formulom:

$$Rso = KT \cdot Ra \quad (2)$$

gde je K_T – koeficijent vedrine neba ili transmisioni indeks.

Korekcija vrednosti solarne radijacije urađena je po formuli:

$$Rs=a \cdot Ra \quad (3)$$

gde je a − korekcioni koeficijent (1,02).

Metoda Turc zasnovana je na korelaciji između potencijalne evapotranspiracije i srednje temperature vazduha i dnevnog trajanja osunčanosti (ili solarne radijacije) ustanovljenoj merenjem na lizimetru u Versaju, Francuska (Turc, 1961). Standardnu kulturu ove metode predstavlja travni pokrivač (košena livada) visine 12−20 cm, površine veće od 6 ha u optimalnim uslovima vlaženja.

$$ETp=0,40 \cdot (Ig+50) \cdot \frac{T}{T+15} \quad (4)$$

gde je: ETp − potencijalna evapotranspiracija (mm·mesec^{-1}); Ig − globalna radijacija (cal·cm^{-2} ·dan^{-1}); T − srednja dnevna temperatura (^{o}C) koja se računa kao prosek maksimalne i minimalne temperature vazduha.

Metoda Priestley-Taylor je pojednostavljena verzija kombinovane metode Penman, koja ne koristi aerodinamičku komponentu kombinovane metode, dok se energetska komponenta množi koeficijentom α_t. Metoda Priestley-Taylor važi za evapotranspiraciju sa velike vlažne površine:

$$ETp = \alpha t \cdot \frac{\Delta}{\Delta+\gamma} \cdot (Rn - G) \quad (5)$$

gde je: ETp − potencijalna evapotranspiracija (mm·dan^{-1}); αt − koeficijent; Δ− pad napona zasićene vodene pare (mb·°K^{-1}); γ− psihrometrijska konstanta (mb·°K^{-1}); Rn − neto radijacija (mm·dan^{-1}); G − toplotni fluks zemljišta (mm·dan^{-1}).

Metoda Hargreaves koristi podatke o temperaturi vazduha kao ulazne podatke. Namenjena je za mesečni ili dekadni period izračunavanja evapotranspiracije,

$$ETo = 0,0023 \cdot Ra \cdot (Tmax - Tmin)^{0,5} \cdot (T + 17,8) \quad (6)$$

gde je: ETo − referentna evapotranspiracija (mm·dan^{-1}); Ra − ekstraterestrijalna radijacija (mm·dan^{-1}); Tmax – maksimalna temperatura vazduha (°C); Tmin – minimalna temperatura vazduha (°C); T − srednja dnevna temepratura (°C).

Metoda modifikovani Hargreaves je preporučena za uslove humidne klime, jer se primenom originalne metode Hargreaves dobijaju veće vrednosti evapotranspiracije nego metodom FAO56-PM. Modifikacija se sastoji u promeni eksponenta na vrednost od 0,424 (Trajković, 2007b). Izraz za metodu modifikovani Hargreaves je sledeći:

$$ETo = 0,0023 \cdot 0,408 \cdot Ra \cdot (Tmax - Tmin)^{0,424} \cdot (\frac{Tmax-Tmin}{2} + 17,8) \quad (7)$$

gde je: Ra − ekstraterestrijalna radijacija (MJ·m^{-2}·dan^{-1}).

Metoda Copais je razvijena za proračun ETo u uslovima mediteranske klime (Copais, Grčka). Prvobitno je namenjena za proračun ETo za vremenski interval od jednog časa i koristi podatke o temperaturi vazduha, solarnoj radijaciji i relativnoj vlažnosti vazduha (Alexandris i Kerkides, 2003). Za proračun na dnevnom nivou, izraz za metodu Copais glasi:

$$ETo=m1+m2C2+m3C3+m4C1C2 \quad (8)$$

gde koeficijenti imaju sledeće vrednosti: $m_1 = 0{,}057$, $m_2 = 0{,}277$, $m_3 = 0{,}643$, $m_4 = 0{,}0124$;

$$C1 = 0{,}64146 - 0{,}00784 \cdot RH + 0{,}372 \cdot Rs - 0{,}00264 \cdot Rs \cdot RH \quad (9)$$

$$C2 = -0{,}0033 + 0{,}00812 \cdot T + 0{,}101 \cdot Rs + 0{,}00584 \cdot Rs \cdot T \quad (10)$$

Hamon (1961) je predstavio metodu za proračun potencijalne evapotranspiracije:

$$ETp = k \cdot 0{,}165 \cdot 216{,}7 \cdot N \cdot \left(\frac{es}{T+273{,}3}\right) \quad (11)$$

gde je: ETp − potencijalna evapotranspiracija (mm·dan^{-1}); k-koeficijent = 1; N – maksimalno trajanje sunčevog sjaja u toku dana (časovi); e_s − saturacioni napon vodene pare (mb); T − srednja mesečna temperatura (°C).

Izraz za metodu Makkink glasi:

$$ETo = 0{,}61 \cdot \frac{\Delta}{\Delta+\gamma} \cdot \frac{Rs}{\lambda} - 0{,}12 \quad (12)$$

gde je: ETo − referentna evapotranspiracija (mm·dan^{-1}); λ – 2,45 MJ·kg^{-1}; Rs – neto solarna kratkotalasna radijacija (MJ·m^{-2}·dan^{-1}).

Analizirano područje

Za proračun su korišćeni klimatski podaci za period od 2010. do 2013. godine, sa meteoroloških stanica: Niš, Beograd, Novi Sad, Loznica, Vranje, Zlatibor, Ćuprija i Kikinda. Meteorološke stanice su raspoređene na različitim nadmorskim visinama i obuhvataju različite geografske širine (tabela 1), pa se na osnovu podataka sa ovih stanica dobija uvid u klimatske prilike u Srbiji.

Tabela 1. Opis meteoroloških stanica.
Table 1. Description of meteorological stations.

Stanice *Stations*	Geografska širina *Latitude* (°N)	Nadmorska visina *Altitude* (m)	Maksimalna temperatura vazduha *Maximum air temperature* (°C)	Minimalna temperatura vazduha *Minimum air temperature* (°C)	Relativna vlažnost vazduha *Relative humidity* (%)	Brzina vetra *Wind speed* (m/s)
Niš	43,33	204	18,86	7,48	68,28	1,14
Beograd	44,8	132	18,22	9,39	66,21	2,53
Novi Sad	45,32	86	17,46	7,12	75,71	2,55
Zlatibor	43,73	1029	13,75	4,76	74,78	1,72
Vranje	42,55	433	18,15	6,09	69,69	1,88
Loznica	44,53	121	18,30	7,65	73,23	1,04
Čuprija	43,93	123	19,16	6,32	74,22	1,30
Kikinda	45,85	81	17,11	6,91	73,11	3,03

Statistički parametri

Za upoređivanje i rangiranje metoda korišćeni su sledeći parametri: maksimalno apsolutno odstupanje (engl. *maximum absolute difference* − MXE), srednje apsolutno odstupanje (engl. *mean absolute difference* − MAE), kvadratni koren odstupanja (engl. *root-mean-square difference* − RMSD), prilagođeni kvadratni koren odstupanja (engl. *adjusted-root-mean-square difference* − ARMSD), otežani kvadratni koren odstupanja (engl. *weighed root-mean-square difference* − WRMSD), regresioni koeficijenti b i a i koeficijent determinacije R^2. Parametri su izračunati na osnovu sledećih formula:

$$MXE = max\ (|Etpm, i - Eteq, i|)^{M}{}_{i=1} \quad (13)$$

$$MAE = \frac{\sum_{i=1}^{n}(|ETpm,i-ETeq,i|)}{n} \quad (14)$$

$$RMSD = \left[\frac{\sum_{i=1}^{n}(|ETpm,i-ETeq,i|)^2}{n}\right]^{0,5} \quad (15)$$

$$ARMSD = \left[\frac{\sum_{i=1}^{n}(|ETpm,i-b\cdot ETeq,i|)^2}{n}\right]^{0,5} \quad (16)$$

$$\text{WRMSD}=0{,}7\cdot(0{,}67\cdot\text{RMSD}+0{,}33\cdot\text{ARMSD})+0{,}3\cdot(0{,}67\cdot\text{pRMSD}+0{,}33\cdot\text{pARMSD})\text{Eq.} \quad (17)$$

gde je: ETpm – vrednost evapotranspiracije dobijena fomulom FAO56-PM; ETeq – vrednost evapotranspiracije dobijena odgovarajućom metodom koja se upoređuje sa FAO56-PM; n – broj posmatranja.

Relacija između FAO56-PM i upoređivane metode data je preko linearne regresije,

$$Y = bx + a \quad (18)$$

$$b = \frac{\sum_{i=1}^{n}(xi-\bar{x})(yi-\bar{y})}{\sum_{i=1}^{n}(xi-\bar{x})^2} \quad (19)$$

$$a = \bar{y} + b\bar{x} \quad (20)$$

gde su: b i a regresioni koeficijenti, x_i – mesečna vrednost evapotranspiracije dobijena formulom FAO56-PM; y_i − vrednost evapotranspiracije dobijena odgovarajućim metodama koja se upoređuje sa FAO56-PM; $\bar{x}$ i $\bar{y}$ – aritmetičke sredine.

Rezultati i diskusija

Statistička analiza poređenja dnevnih vrednosti ETo dobijenih ispitivanim metodama, sa metodom FAO56-PM, na svim izabranim meteorološkim stanicama za period 2010−2013, prikazana je u tabeli 2.

Tabela 2. Statistička analiza dnevnih vrednosti ETo (2010−2013) dobijenih ispitivanim metodama, u poređenju sa metodom FAO56-PM (RMSD − kvadratni koren odstupanja, ARMSD − prilagođeni kvadratni koren odstupanja, WRMSD − otežani kvadratni koren odstupanja, MAE − srednje apsolutno odstupanje, MXE − maksimalno apsolutno odstupanje, b − regresioni koeficijent, R^2 − koeficijent determinacije).

Table 2. Statistical analysis of daily values − of ETo (2010−2013) obtained by tested methods, compared to the FAO56-PM method (RMSD − root-mean-square difference, ARMSD − adjusted-root-mean-square difference, WRMSD − weighed root-mean-square difference, MAE − mean absolute difference, MXE − maximum absolute difference, b − coefficient of regression, R^2 − coefficient of determination).

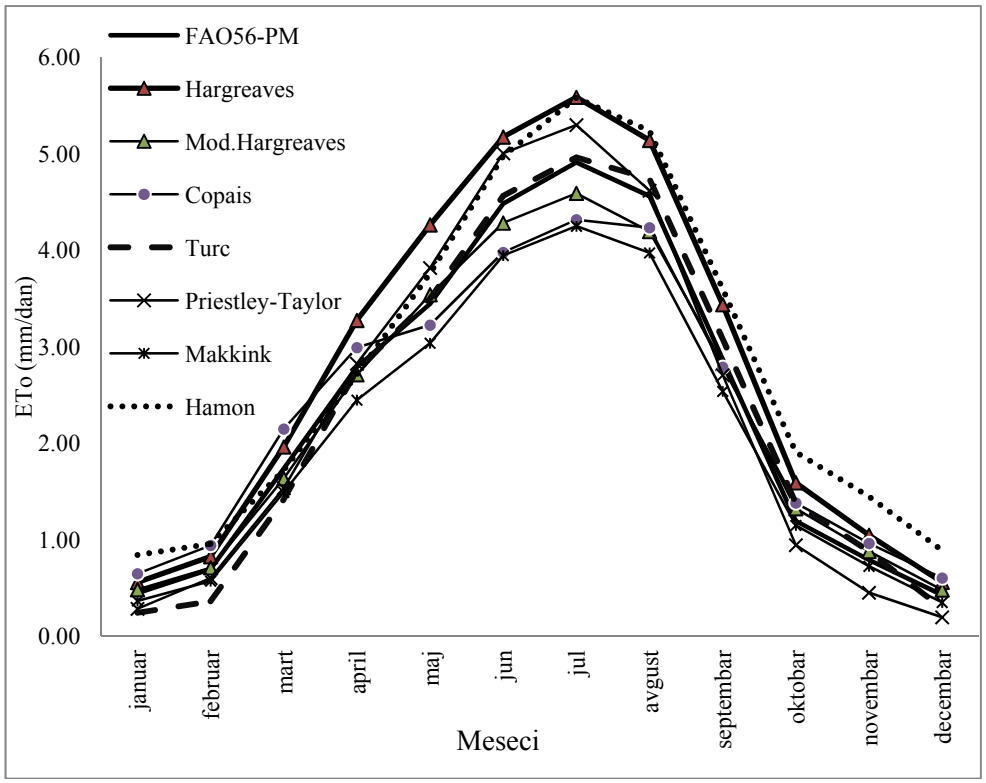
Metode *Methods*	Stanice *Stations*	RMSD	ARMSD	WRMSD	MAE	MXE	b	R^2	Odstupanje *Deviation*%
Hargreaves	Niš	1,10	1,90	1,40	1,21	2,71	1,23	0,92	22,86
	Beograd	0,61	0,66	0,84	0,38	4,16	0,92	0,91	-8,25
	Novi Sad	0,66	0,70	0,75	0,44	4,10	1,02	0,93	1,75
	Loznica	0,88	1,16	0,96	0,77	3,33	1,09	0,92	9,46
	Vranje	0,79	1,04	0,89	0,63	2,85	1,08	0,94	7,81
	Zlatibor	0,49	0,46	0,58	0,25	2,30	0,97	0,93	-2,59
	Ćuprija	0,93	1,24	1,12	0,87	3,33	1,10	0,90	9,53
	Kikinda	0,56	0,54	0,78	0,31	2,62	0,95	0,93	-5,37
Mod.Hargreaves	Niš	0,56	0,54	0,66	0,31	2,38	0,99	0,92	-1,00
	Beograd	0,82	1,37	1,30	0,66	5,04	0,75	0,91	-24,77
	Novi Sad	0,56	0,86	0,87	0,31	4,71	0,82	0,93	-17,53
	Loznica	0,51	0,56	0,68	0,26	2,23	0,89	0,93	-11,42
	Vranje	0,49	0,68	0,76	0,24	2,26	0,86	0,94	-13,72
	Zlatibor	0,50	0,83	0,80	0,25	2,16	0,80	0,93	-20,01
	Ćuprija	0,61	0,75	0,91	0,38	3,18	0,87	0,90	-12,73
	Kikinda	0,71	1,22	1,18	0,51	2,95	0,77	0,93	-23,04
Copais	Niš	0,62	0,58	0,61	0,39	2,13	0,94	0,88	-6,30
	Beograd	0,69	0,89	0,85	0,47	3,12	0,85	0,88	-14,72
	Novi Sad	0,61	0,86	0,79	0,37	3,33	0,84	0,91	-16,41
	Loznica	0,61	0,65	0,64	0,38	2,30	0,89	0,88	-11,08
	Vranje	0,59	0,62	0,62	0,35	1,90	0,91	0,90	-9,32
	Zlatibor	0,57	0,54	0,58	0,33	1,98	0,95	0,89	-5,20
	Ćuprija	0,72	1,22	1,05	0,52	6,70	0,76	0,91	-23,76
	Kikinda	0,65	1,01	0,90	0,42	2,17	0,82	0,92	-18,39
Turc	Niš	0,56	0,90	0,68	0,32	2,30	1,13	0,94	13,31
	Beograd	0,54	0,55	0,55	0,29	2,40	1,02	0,93	2,38
	Novi Sad	0,50	0,50	0,58	0,25	2,81	1,00	0,94	0,23
	Loznica	0,53	0,65	0,55	0,28	2,05	1,06	0,94	6,01
	Vranje	0,43	0,51	0,44	0,19	2,15	1,05	0,96	5,42
	Zlatibor	0,42	0,59	0,52	0,18	1,77	1,10	0,93	10,37
	Ćuprija	0,55	0,62	0,71	0,30	6,07	0,94	0,93	-6,04
	Kikinda	0,48	0,51	0,59	0,23	2,10	0,97	0,95	-2,77

Tabela 2. Nastavak.
Tabele 2. Continuation.

Metode *Methods*	Stanice *Stations*	RMSD	ARMSD	WRMSD	MAE	MXE	b	R^2	Odstupanje *Deviation*%
PT	Niš	0,44	0,66	0,54	0,19	1,93	1,10	0,96	10,34
	Beograd	0,72	0,75	0,86	0,52	4,15	0,96	0,90	-3,94
	Novi Sad	0,57	0,68	0,64	0,32	3,83	1,07	0,93	6,63
	Loznica	0,50	0,84	0,68	0,25	2,46	1,13	0,96	12,89
	Vranje	0,42	0,46	0,47	0,17	2,49	1,04	0,96	3,64
	Zlatibor	0,50	0,70	0,58	0,25	1,94	1,10	0,94	9,82
	Ćuprija	0,64	0,64	0,77	0,40	3,31	1,00	0,91	-0,25
	Kikinda	0,56	0,56	0,64	0,31	2,80	1,00	0,93	0,36
Makkink	Niš	0,41	0,54	0,52	0,17	2,44	0,91	0,95	-9,05
	Beograd	0,74	0,68	0,82	0,55	2,53	0,96	0,90	-4,09
	Novi Sad	0,57	0,85	0,79	0,32	4,02	0,86	0,94	-14,40
	Loznica	0,44	0,57	0,52	0,20	2,83	0,90	0,94	-9,60
	Vranje	0,51	0,82	0,71	0,26	2,54	0,86	0,96	-14,31
	Zlatibor	0,54	0,60	0,65	0,29	1,85	0,86	0,91	-14,35
	Ćuprija	0,77	1,23	1,14	0,59	6,90	0,79	0,92	-21,35
	Kikinda	0,72	1,18	1,07	0,52	2,93	0,80	0,95	-19,72
Hamon	Niš	1,05	1,43	1,26	1,11	3,42	1,12	0,92	11,69
	Beograd	0,79	1,25	1,16	0,63	4,61	0,80	0,92	-20,28
	Novi Sad	0,76	0,67	0,83	0,58	2,52	0,93	0,90	-6,83
	Loznica	0,97	0,96	1,01	0,95	3,55	0,99	0,88	-0,59
	Vranje	0,68	0,61	0,75	0,46	2,97	0,91	0,91	-9,41
	Zlatibor	0,36	0,47	0,42	0,13	1,70	0,92	0,96	-8,25
	Ćuprija	0,74	0,66	0,84	0,54	2,83	0,95	0,90	-4,51
	Kikinda	0,68	0,67	0,84	0,46	2,75	0,90	0,90	-10,2

Metoda Hargreaves je pokazala veliko odstupanje od metode FAO56-PM po parametrima RMSD i b (tabela 2). Parametar RMSD se kreće od 1,10 mm·dan^{-1} (Niš), do 0,49 mm·dan^{-1} (Zlatibor). Odstupanje vrednosti ETo od vrednosti FAO56-PM su od 1,75% (b = 1,02) (Novi Sad) do 23% (b = 1,23) (Niš). Allen et al. (1998) su predložili metodu Hargreaves kao alternativnu metodu proračuna evapotranspiracije u slučaju nedostatka klimatskih podataka za proračun po metodi FAO56-PM. Na nedostatke ove formule, kao i dobijanje značajno većih vrednosti ETo u odnosu na FAO56-PM, ukazali su i Allen i Pruitt (1988), Todorovic et al. (2013), Trajkovic (2005), Trajkovic i Kolakovic (2009), Alexandris et al. (2008). Allen (1997) je izneo zaključak da nije moguće samo sa jednim koeficijentom tačno odrediti Rs na osnovu Tmax i Tmin, već da taj koeficijent varira u zavisnosti od područja. Ta činjenica ukazuje da se korišćenjem ove metode mogu dobiti velika odstupanja od realnih vrednosti evapotranspiracija. Istraživanja sprovedena za potrebe ovog rada pokazuju da su na prosečnom mesečnom nivou odstupanja od

FAO56-PM takođe velika i iznose 17,8% (slika 1). U uslovima humidne i subhumidne klime (kojima pripadaju rejoni posmatranih meteoroloških stanica), ne preporučuje se upotreba ove metode (Todorovic et al., 2013).



Slika 1. Prosečne mesečne vrednosti ETo (2010−2013) sa osam meteoroloških punktova u Srbiji, dobijene primenom različitih metoda.

Figure 1. Average monthly values − of ETo (2010−2013) from eight meteorological stations in Serbia, obtained by applying different methods.

Na osnovu rezultata analize dnevnih vrednosti ETo za period 2010−2013, najbolje slaganje metodom modifikovani Hargeraves dobijeno je za meteorološku stanicu Niš (odstupanje je 1%, b = 0,99). U slučaju drugih lokaliteta, vrednosti ETo dobijene metodom modifikovani Hargreaves su za 12−25% niže od vrednosti dobijenih metodom FAO56-PM. Vrednosti parametra RMSD su se kretale u intervalu od 0,49 mm·dan^{-1} (Vranje) do 0,82 mm·dan^{-1} (Beograd). Metoda modifikovani Hargreaves razvijena je nakon regionalne kalibracije i izmenom eksponenta na 0,424, za klimatske uslove

Srbije sa prosečnom brzinom vetra 1,3 $m \cdot s^{-1}$ (Trajkovic, 2007b), pa jedan od razloga odstupanja može biti prosečna brzina vetra na posmatranim područjima, koja se razlikuje od one uzete za kalibraciju. Na prosečnom mesečnom nivou, metoda je pokazala znatno bolje slaganje sa FAO56-PM (odstupanje 2,5%) (slika 1), jer je ova metoda namenjena za proračun na mesečnom, odnosno dekadnom nivou.

Metoda Copais je pokazala bolje rezultate slaganja sa FAO56-PM na prosečnom mesečnom nego na dnevnom nivou (tabela 2, slika 1). Vrednosti parametra RMSD za metodu Copais su 0,57−0,72 $mm \cdot dan^{-1}$ (tabela 2). Najmanje odstupanje od 5% dobijeno je za meteorološku stanicu Zlatibor (b = 0,95), RMSD 0,57 $mm \cdot dan^{-1}$. Na svim stanicama metoda je dala vrednosti ETo koje su za 5−24% manje od vrednosti dobijenih metodom FAO56-PM. Metoda Copais je razvijena u uslovima semiaridne klime, prvobitno za proračun ETo na časovnom nivou, a zatim modifikovana za proračun na dnevnom nivou. Alexandris et al. (2003, 2006) su dobili odstupanje za u proseku 3% (na časovnom nivou) i 7% (na dnevnom nivou) pri poređenju metode Copais sa FAO56-PM.

Metoda Turc je pokazala dobro slaganje sa metodom FAO56-PM na većini lokaliteta (tabela 2). Vrednosti parametra RMSD su od 0,42 do 0,56 $mm \cdot dan^{-1}$, dok su odstupanja 0,23−13,3%. Najbolji rezultati na osnovu parametara b postignuti su na stanici Novi Sad, odstupanje je 0,23% (b = 1,0023). Metoda Turc ne uzima u obzir brzinu vetra, pa su Trajkovic i Kolakovic (2007c) predložili modifikovanu metodu koja koristi brzinu vetra. Rezultati su pokazali da izmenjena metoda daje bolje slaganje sa metodom FAO56-PM. Kashyap i Panda (2001) dobili su odstupanje vrednosti metode Turc od lizimetarskih vrednosti od 2,72%. Oni su zaključili da u uslovima subhumidne klime većina metoda, uključujući Turc i Priestley-Taylor, daju veće vrednosti ETo od lizimetarskih, kada je evapotranspiracija mala, dok u slučaju većih vrednosti, metode pokazuju vrednosti koje su niže od lizimetarskih. Primena ove metode preporučuje se u manje vetrovitim područjima umerene klime (Jensen et al., 1990; Trajkovic i Kolakovic, 2009). U uslovima aridne klime, metoda Turc daje vrednosti ETo koje su u proseku 26% veće od vrednosti dobijenih metodom FAO56-PM, pa njena upotreba nije preporučena (Jensen et al., 1990). U našim klimatskim uslovima, na osnovu rezultata drugih istraživača, metoda je pokazala dobro slaganje sa FAO56-PM. Odstupanje od metode FAO56-PM je iznosilo od -5%, na dnevnom nivou (Alexandris et al., 2008), do -10%, na mesečnom nivou (Trajkovic i Kolakovic, 2009).

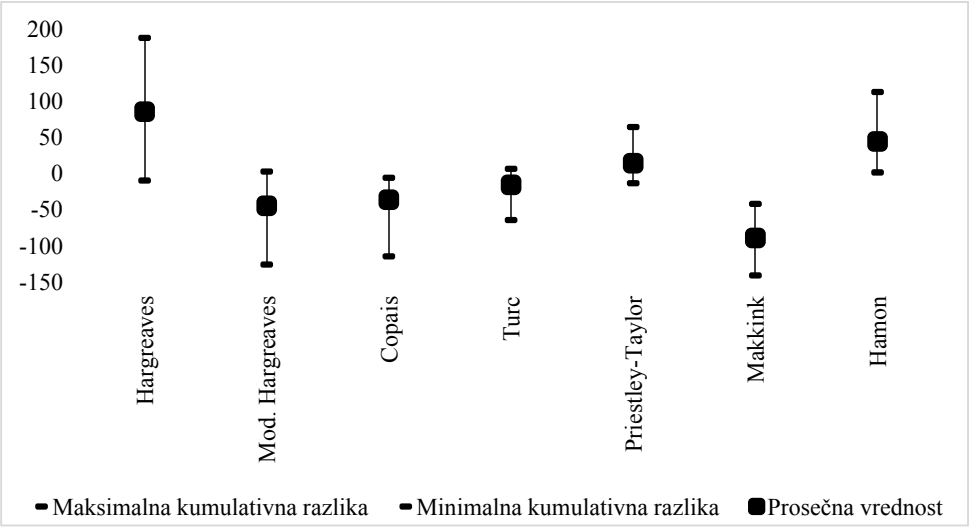
Metoda Priestley-Taylor, u poređenju sa metodom FAO56-PM, dala je minimalna odstupanja na stanicama Ćuprija (-0,25%) i Kikinda (0,36%) (tabela 2), dok je najveće odstupanje dobijeno za stanicu Niš (10%). Vrednosti parametra RMSD kreću su u intervalu od 0,42 do 0,72 $mm \cdot dan^{-1}$. Na osnovu

prosečnih mesečnih vrednosti za osam posmatranih stanica, metoda je dala vrednosti ETo koje su za 0,25% manje od vrednosti dobijenih metodom FAO56-PM (slika 1), što je i najmanje dobijeno odstupanje u odnosu na ostale metode. Ovi rezultati su u skladu sa istraživanjima Alexandris et al. (2008) i Trajkovic i Kolakovic (2009), koji su pokazali da metoda Priestley-Taylor daje zadovoljavajuće rezultate u klimatskim uslovima naše zemlje. Proračun je vršen na mesečnom i dnevnom nivou, a dobijena su odstupanja od -5% do +5%. Metoda postiže dobre rezultate u područjima sa humidnom klimom. Namenjena je za proračun ETo na mesečnom ili dekadnom nivou. Van Kraalingen i Stol (1997) su zaključili da primena metode tokom zimskih meseci nije moguća zbog neto radijacije. Vrednosti neto radijacije u toku zimskih meseci mogu biti negativne, što rezultuje dobijanjem negativne vrednosti ETo pri proračunu, iako je stvarna evapotranspiracija pozitivna. Za unapređenje formule, pri primeni u humidnim krajevima sa većom nadmorskom visinom, Xu i Singh (2002) su predložili korišćenje koeficijenta $\alpha = 0,90$ umesto $\alpha = 1,26$.

Metoda Makkink pokazuje loše slaganje sa metodom FAO56-PM. Vrednosti parametra RMSD iznose od 0,41 do 0,77 $mm \cdot dan^{-1}$. Na svim stanicama metoda je dala vrednosti ETo manje u odnosu na FAO56-PM, od 4 do 21%. Najmanje odstupanje od 4% dobijeno je za stanicu Beograd ($b = 0,96$). Metoda Makkink daje dobre rezultate slaganja u Zapadnoj Evropi, području za koje je razvijena. Za područje naše zemlje i drugi istraživači (Alexandris et al., 2008) su registrovali velika odstupanja (-20%). Manje vrednosti odstupanja su dobijene na prosečnom mesečnom nivou (slika 1) nego na dnevnom nivou.

Rezultati statističkih parametara RMSD i b dobijeni metodom Hamon imaju najveći interval variranja za posmatrane stanice (tabela 2). Vrednosti RMSD su od 0,36 $mm \cdot dan^{-1}$, za stanicu Zlatibor, do 1,05 $mm \cdot dan^{-1}$, za stanicu Niš. Najmanje odstupanje vrednosti ETo dobijeno je za stanicu Loznica, 0,6% ($b = 0,994$), dok je odstupanje za stanicu Beograd bilo 20% ($b = 0,8$). Zbog jednostavnosti korišćenja i malog broja zahtevanih podataka, Lu et al. (2005) navode da se metoda Hamon može koristiti za proračun ETo u slučaju kada ne postoje podaci potrebni za radijacione metode. Na osnovu rezultata svih statističkih parametra (tabela 2) i najvećeg odstupanja na prosečnom mesečnom nivou (18,6%), u poređenju sa svim ostalim metodama (slika 1), primenom metode Hamon ne dobijaju se zadovoljavajući rezultati na području Srbije.

Upoređivanje različitih metoda za izračunavanje ETo sa metodom FAO56-PM rađeno je i na osnovu kumulativne dnevne razlike za letnje mesece 2012. godine (slika 2). Izabrana je 2012. godina, jer su tada zabeležene najveće godišnje sume ETo u posmatranom periodu na svim lokalitetima, a period od 20. aprila do 30. avgusta značajan je sa aspekta navodnjavanja. Biljke su tada u vegetacionoj fazi, pa je najčešće putem navodnjavanja neophodno obezbediti potrebnu količinu vode.



Slika 2. Kumulativne dnevne razlike za letnje mesece (20. april − 30. avgust) 2012. godine.
Figure 2. Cumulative daily differences for summer months (20th of April − 30th of August, 2012).

Najveće odstupanje ETo od metode FAO56-PM u letnjim mesecima pokazale su metode Makkink (Beograd -129 mm, Kikinda -141 mm, Ćuprija -139 mm, Novi Sad -92 mm) i Hargreaves (Niš +187 mm, Loznica +134 mm, Vranje +105 mm, Zlatibor +59 mm). Rezultati kumulativne razlike za period 20. april − 30. avgust dobijeni ovim metodama prate trendove odstupanja dnevnih vrednosti za period 2010−2013. Najmanja kumulativna razlika na stanicama Niš (+23 mm), Vranje (-6 mm), Zlatibor (+7,5 mm) dobijena je metodom Copais. Metode Priestley-Taylor i Turc imaju mali opseg variranja kumulative razlike. Prosečna kumulativna razlika dobijena metodom Turc je 6 mm, a metodom Priestley-Taylor je 14 mm.

Zaključak

Statističkom analizom rezultata indirektnog proračuna evapotranspiracije (2010−2013), dobijenih uz pomoć nekoliko različitih metoda (Hargreaves, modifikovana Hargreaves, Copais, Turc, Priestley-Taylor, Makkink i Hamon), na osam meteoroloških punktova širom Srbije, došlo se do sledećih zaključaka:

- Sve metode su pokazale dobro slaganje sa metodom FAO56-PM na osnovu koeficijenta determinacije R^2 (0,88−0,96).

- Najmanje odstupanje od metode FAO56-PM, na prosečnom mesečnom nivou, pokazala je metoda Priestley-Taylor (-0,24%), zatim slede metode Copais (-0,47 %) i Turc (-0,64%). Od temperaturnih metoda, najbolje slaganje sa FAO56-PM dobijeno je modifikovanom metodom Hargreaves (-2,5%).

- Za potrebe sagledavanja potrošnje i potrebe biljaka za vodom u letnjim mesecima, metode Copais, Turc i Priestley-Taylor mogu se koristiti kao zamena za FAO56-PM u našim klimatskim uslovima. Za proračun ETo ovim metodama potrebni su podaci o dnevnoj insolaciji i relativnoj vlažnosti vazduha, koji nisu uvek dostupni. Kada su poznati samo podaci o temperaturi vazduha, rezultati dobijeni u ovom istraživanju opravdavaju upotrebu modifikovane metode Hargreaves za proračun ETo u toku vegetacionog perioda. Prosečna kumulativna razlika dobijena ovom metodom je -45 mm.

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ANALYSIS OF SEVEN INDIRECT METHODS FOR EVALUATION OF REFERENCE EVAPOTRANSPIRATION UNDER CLIMATE CONDITIONS OF SERBIA

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A b s t r a c t

In order to calculate water deficit of agricultural crops, it is necessary to have an insight into the evapotranspiration process. As for evaluation of reference evapotranspiration, the Penman-Monteith (FAO56-PM) method, suggested by The International Commission on Irrigation and Drainage (ICID) and Food and Agriculture Organization of the United Nations (FAO), requires several climate parameters, which are often unavailable. Thus, in this paper, the methods for computing ETo, which use limited weather data, were tested and then compared to FAO56-PM. The selected methods were those most often used as the replacement for FAO56-PM: Hargreaves, adjusted Hargreaves, Copais, Turc, Priestley-Taylor, Makkink and Hamon. ETo was calculated at the daily and average monthly levels, for the 2010−2013 period, using data from the following meteorological stations: Niš, Belgrade, Novi Sad, Loznica, Valjevo, Zlatibor, Ćuprija and Kikinda. Special importance was given to the vegetation period during the dry season due to the application of irrigation. The comparison of methods was based on statistical analysis, using parameters: MXE, MAE, RMSD, ARMSD, WRMSD, b and R^2. The highest rate of matching FAO-PM at the average monthly level, as well as during the 2012 growing season, was shown by Copais, Turc and Priestley-Taylor methods, thus these methods may be recommended as the replacement for FAO-PM under climate conditions of Serbia. In case only temperature data are available, the results of this research justify the use of the adjusted Hargreaves equation to calculate ETo for the vegetation period.

Key words: reference evapotranspiration, FAO-56 Penman-Monteith, Turc, Priestley-Taylor, Hargreaves, adjusted Hargreaves, Copais, Hamon, humid and subhumid climate.

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ON THE FERTILIZER PARTICLE MOTION ALONG THE VANE OF A CENTRIFUGAL SPREADER DISC ASSUMING PURE SLIDING OF THE PARTICLE

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Abstract: At present, spreading of mineral fertilizers in Europe is most commonly performed using centrifugal disk spreaders with attached vanes. The motion of an ideal spherical homogeneous fertilizer particle along the straight vane attached to a flat rotating disc was analyzed in this paper. The analysis was performed in the non-inertial reference coordinate system. From the assumptions introduced to enable analytical describing of the real particle motion as well as the general tools of solid mechanics, the ordinary in-homogenous second-order differential equation having constant coefficients arose. Its solution represents an approximation of the real relative motion of the fertilizer particle along the straight radial vane fixed to the flat horizontal disc rotating at a constant angular velocity. However, the solution of this kind can be very useful for the optimization of centrifugal spreader working parameters.

Key words: fertilizer particle, centrifugal disc spreader, radial vanes, differential equation.

Introduction

Different kinds of solid fertilizer spreaders have been designed in the past. However, it seems that centrifugal disc spreaders (Figure 1) are the most popular fertilizing machines worldwide, as well as in Serbia. Their main advantages in comparison with other available designs lie in lower costs, simple design and maintenance, followed by large soil covering width per single pass (Villette et al., 2008), over 45 [*m*] (Cool et al., 2016).

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A functional principle of the centrifugal fertilizer spreader is simple. The force of gravity pulls particles downward, toward the bottom hopper orifice, placed beyond the disk spinner eccentrically toward the rotation axis. After leaving the hopper, particles fall down on the spinner, establishing contact with an attached vane and a disc (Figure 1). This occurrence starts the second phase of particle moving, controlled by a rotating vane, until particle ejection into the air. Leaving the disc ends the second phase of a particle spreading process and starts the third (the last) phase. It assumes a free ballistic particle flight through the air, until its landing on the ground.

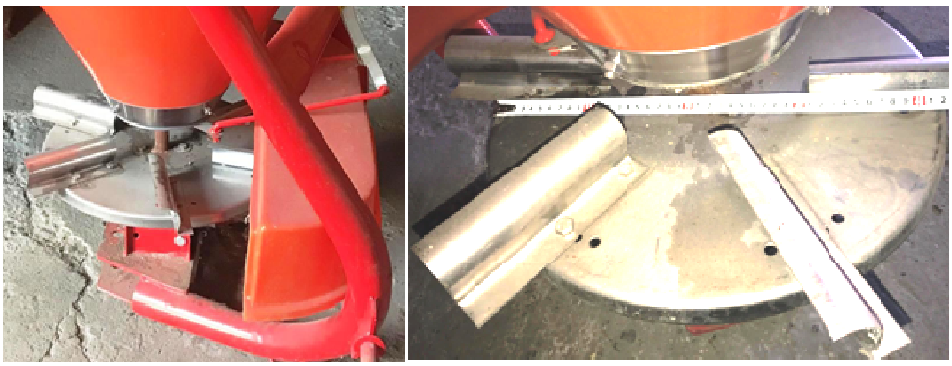

Figure 1. A centrifugal fertilizer spreader, having a flat disc with straight radial vanes.

Obviously, an adequate control of a fertilizer particle moving in the second spreading phase (traveling along the disk vane) should provide the optimal particle velocity vector at the leaving point from the vane. This vector represents the important input data for ballistic models and influences the free flight of the particle through the air and the fertilizer spreading pattern. This velocity can be either predicted using the suitable mechanical model, or measured by the appropriate experimental set-up.

This paper presents a possible approach among many other less or more similar or quite different methods for analysis and predicting the fertilizer spreading process by centrifugal (spinning) disc spreaders with radial vanes. Modelling of this kind has been intensified since the middle of the 20th century. For example, Cunningham (1962), Cunningham and Chao (1967), Dobler and Flatow (1968) have researched the particle motion along the vane. Among others, Mennel and Reece (1962), Griffis et al. (1983) have analyzed the ballistic flight of the fertilizer particle through the air.

Selecting and integrating previously published partial models, Olieslagers et al. (1996) made a more generalized model, which provided the increased prediction accuracy of the solid fertilizer particle spreading. The model was verified

experimentally, applying the traditional simple test method, namely the "collection tray method". According to this method, while the machine passes the rows of collection trays (placed perpendicular to the travel direction) at a constant travel speed, the fertilizer particles are collected at different transverse positions. After weighing the amount of fertilizer in each tray of each row, the spatial distribution pattern over the experimental plot surface can be composed.

Further improvement of the fertilizer spreading models has been continued in the 21st century: Aphale et al. (2003), Dintwa et al. (2004), Villette et al. (2005), Cool et al. (2014), Cool et al. (2016), etc. However, these models have been based on the assumption that particles do not interact mutually, which may cause prediction errors. In order to improve the predicting accuracy, an alternative approach has been introduced. Methods of this kind include the particle interactions in a modelling algorithm using the numerical mathematics – primarily discrete element methods: Tijskens et al. (2005), Van Liedekerke et al. (2009), etc. Unfortunately, quantitative simulations based on this method need physical fertilizer characteristics as input data, which are at present difficult to measure (Villette et al., 2008).

This work presents an analytical solution of the dynamic model that describes the motion of a fertilizer particle along the radial vane of the centrifugal spreader disc. This motion was analyzed in the non-inertial reference system fixed to the spinning disc (Figure 3). Therefore, the carrying motion was accounted by introducing the appropriate inertial forces. To facilitate the problem related to the mathematical apparatus needed, a number of assumptions have been introduced in the mechanical model of particle motion. Consequently, the resulting equations and their solutions represent an appropriate approximation of the real motion, which enables the analysis of working parameters that govern the fertilizer spreading process.

Materials and Methods

Dynamics of a single fertilizer particle movement along a straight radial vane attached to the horizontal flat spinning disc of a centrifugal spreader was analyzed in this paper. Thus, only the first phase of a fertilizer spreading process was comprehended, i.e. the model considered the motion of the particle along the vane, until it dropped out. A particle motion model is based on the assumption of continuous motion of a single particle along the vane, and laws of theoretical mechanics (Beer et al., 2010; Hibbeler, 2010).

The focus of interest of this manuscript is the dynamic equation of the fertilizer particle motion. In this particular case, the non-homogeneous second-order differential equation of motion was solved analytically following methods of mathematical analysis (Soare et al., 2007). The solution was applied on specific data, processed using MS Excel.

The last phase of a spreading process, the ballistic flight of the fertilizer particle through the atmospheric air until its lending, has not been analyzed. However, this model provides an additional insight in the fertilizer particle moving over the spinning disc and its velocity vector at the leaving point from the vane. The information on this velocity vector is important, because it influences the flight of the particle through the air and the fertilizer spreading pattern.

Results and Discussion

The analytical model of the fertilizer particle motion is based on various assumptions.

An individual fertilizer particle moves along the vane, mounted radially on the horizontal flat disk. Thus, particle interactions were neglected and achieved results approximated the real spreading process (Villette et al., 2008).

The spreading disc is rotating at a constant angular velocity $\omega_D[s^{-1}]$.

Fertilizer particles are ideally spherical homogeneous particles, having constant density.

Dynamics of the spherical particle on the spreading disc is based on the approximation of pure sliding against the vane.

According to Olieslagers et al. (1996), Aphale et al. (2003), Dintwa et al. (2004), particles bouncing over the disc are negligible: tight continual contact between the observed particle and the vane is established along the whole particle travel over the disc.

The particle motion follows the well-known Newton's second law:

$$m \cdot \overrightarrow{a^{a}} = \frac{d\overrightarrow{v^{a}}}{dt} = \frac{d^2\overrightarrow{r^{a}}}{dt^2} = \ddot{\vec{r}}^{a} = \sum_{i=1}^{n} \vec{F}_i \,, \tag{1}$$

where $m\,[kg]$ is the particle mass, $\vec{F}_i[N](i=1,2,...,n)$ are forces acting on it and $\overrightarrow{a^{a}}[m \cdot s^{-2}]$ is the absolute linear acceleration (i.e. the first derivative of the absolute velocity vector $\overrightarrow{v^{a}}$) and the second derivative of the position vector $\overrightarrow{r^{a}}$ of the particle in the inertial reference coordinate system *Oxyz* (Figure 2).

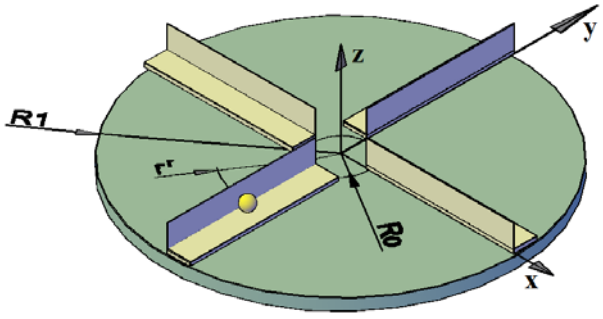

Figure 2. Inertial coordinate system.

Nomenclature:
R_0, R_1 the entrance radius of the particle and the external radius of the rotating disc [m];
r^r the radial distance from the disc center in the rotating (relative) system O$\xi\eta\zeta$ [m];
x,y,z the coordinates of a fertilizer particle in the inertial coordinate system [m].
Nomenclature:
$\vec{F}_{FD}, \vec{F}_{FV}$ the friction forces between the particle and the disc and the vane, [N];
$\vec{F}_{CF}$ the centrifugal force exerted on the fertilizer particle [N];
$\vec{F}_{COR}$ the Coriollis force exerted on the fertilizer particle [N];
$\vec{G}, \vec{g}$ the gravitational force [N] and acceleration [$m \cdot s^{-2}$] of the particle;
m the mass of fertilizer particle [kg];
$\vec{N}_D$, $\vec{N}_V$ the orthogonal forces of the disc and the vane exerted on the particle [N];
ξ, η, ζ the coordinates in the non-inertial relative system fixed to the disk [m];
ω_D the angular velocity of the rotating disc [s^{-1}].

However, the traveling of the particle is considered in the relative reference system $O\xi\eta\zeta$ (Figure 3), fixed to the center of a spreading disc and rotating together with the vane along which the observed fertilizer particle moves. Therefore, the coordinate system $O\xi\eta\zeta$ is a non-inertial reference system. This means that Newton's second law can be applied only by introducing the additional imaginary "inertial" forces: the centrifugal $\vec{F}_{CF}$ [N] and Coriollis forces $\vec{F}_{COR}$ [N] (Figure 3).

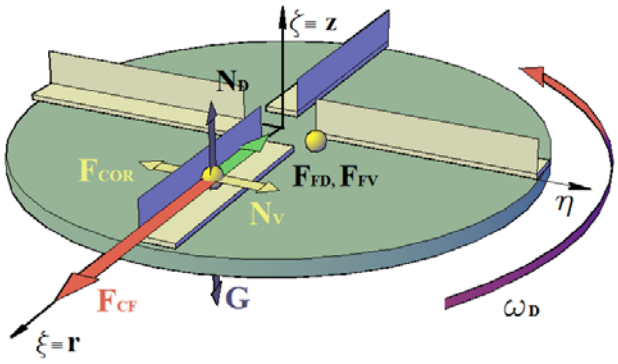

Figure 3. Forces exerted on the particle in the relative reference system.

The following real forces also act on the particle: the friction forces exerted by the rotating disc $\vec{F}_{FD}$[N] and the vane $\vec{F}_{FV}$[N], particle weight $\vec{G}$ [N], orthogonal reactions of the disc $\vec{N}_D$ [N] and the vane $\vec{N}_V$ [N].

Thus, the motion of a fertilizer particle can be described by the vector differential equation:

$$m \cdot \frac{d^2\vec{r^r}}{dt^2} = \vec{F}_{FD} + \vec{F}_{FV} + \vec{F}_{CF} + \vec{G} + \vec{N}_D + \vec{N}_V + \vec{F}_{COR}, \qquad (2)$$

and represented in the relative coordinate system O$\xi\eta\zeta$ by three scalar equations:

$$\boldsymbol{\xi} \equiv \boldsymbol{r}^r\text{: } m \cdot \frac{d^2 r^r}{dt^2} = -F_{FD} - F_{FV} + F_{CF}; \tag{3}$$

$$\boldsymbol{\eta}\text{: } 0 = N_V - F_{COR} \Longrightarrow N_V = F_{COR}; \tag{4}$$

$$\boldsymbol{\zeta} \equiv z\text{: } 0 = N_D - G \Longrightarrow N_D = G. \tag{5}$$

Equations (3), (4) and (5) govern the relative motion of the particle. To be solved, it is necessary to previously evaluate unknown intensities of forces exerting on the particle.

Particle weight is the multiple of the mass m [N] and the gravitational acceleration g [$m \cdot s^{-2}$]. It is vertically aligned, but oriented downward, opposite to the axis O$\boldsymbol{\zeta}$:

$$\vec{G} = m \cdot \vec{g} = -m \cdot g \cdot \overrightarrow{\boldsymbol{\zeta_0}}. \tag{6}$$

The Coriollis force originates from the combined particle motion in the rotating coordinate system. It depends on the carrying angular velocity $\overrightarrow{\omega^c}$, which is the disk angular velocity $\overrightarrow{\omega_D}$, and the relative linear velocity $\overrightarrow{v^r}$ of the particle along the vane (Figure 2):

$$\vec{F}_{\mathrm{COR}} = -2 \cdot m \cdot \left(\vec{\omega}_{\mathrm{D}} \times \overrightarrow{v^r}\right) = -2 \cdot m \cdot v^r \cdot \omega_{\mathrm{D}} \cdot \overrightarrow{\boldsymbol{\eta_0}}, \tag{7}$$

where $\overrightarrow{\boldsymbol{\eta_0}}$ is the unity ort-vector defining the direction of the axis O$\boldsymbol{\eta}$.

The orthogonal vane reactive force on the particle $\vec{N}_V$ is the reaction on the influence of the Coriollis force $\vec{F}_{\mathrm{COR}}$ of the particle against the vane. Hence, these two forces are collinear but of opposite direction. It follows from equations (4) and (7) that this force (Figure 2) is:

$$\overrightarrow{N_{\mathrm{V}}} = -\vec{F}_{\mathrm{COR}} = -(-2 \cdot m \cdot v^r \cdot \omega_{\mathrm{D}} \cdot \overrightarrow{\boldsymbol{\eta_0}}) = 2 \cdot m \cdot v^r \cdot \omega_{\mathrm{D}} \cdot \overrightarrow{\boldsymbol{\eta_0}} \tag{8}$$

Similarly, the vector $\overrightarrow{N_D}$ is the orthogonal reaction of a spreading disc on the fertilizer particle, caused by the particle weight $\vec{G}$ (active force). Therefore, these two forces are collinear but take opposite directions. Regarding equations (5) and (6), it follows that the vector of this force (Figure 2a) is:

$$\overrightarrow{N_{\mathrm{D}}} = -\vec{G} = m \cdot g \cdot \vec{\boldsymbol{k}} = m \cdot g \cdot \overrightarrow{\boldsymbol{\zeta_0}}. \tag{9}$$

The centrifugal force,

$$\vec{F}_{CF} = m \cdot \omega_D^2 \cdot r^r \cdot \overrightarrow{\boldsymbol{\xi_0}}, \tag{10}$$

depends on the particle mass m $[kg]$, its current radius r^r $[m]$ along the vane (the distance from the axis of disc rotation $O_\zeta \equiv Oz$), and the disc angular velocity ω_D $[s^{-1}]$.

The friction forces F_{FD} and F_{FV} are caused by simultaneous sliding of the particle over the spreading disc and vane. They are functions of the dynamic friction coefficients μ_D $[-]$, μ_V $[-]$, and normal reactions N_D $[N]$, N_V $[N]$:

$$F_{FD} = \mu_D \cdot m \cdot g, \tag{11}$$

$$F_{FV} = 2 \cdot \mu_V \cdot m \cdot \omega_D \cdot v^r. \tag{12}$$

Including equations (10), (11) and (12) in the equation (3) gives the second-order linear inhomogeneous ordinary differential equation with constant coefficients, which describes the relative particle motion:

$$\frac{d^2 r^r}{dt^2} + 2 \cdot \mu_V \cdot \omega_D \cdot \frac{dr^r}{dt} - \omega_D^2 \cdot r^r = -\mu_D \cdot g. \tag{13}$$

A general solution of the inhomogeneous differential equation can be found as the sum of the solution of the homogeneous equation r_h^r and a particular solution of the inhomogeneous equation r_p^r

$$r^r = r_h^r + r_p^r. \tag{14}$$

The homogeneous part of this ordinary differential equation is

$$\frac{d^2 r^r}{dt^2} + 2 \cdot \mu_V \cdot \omega_D \cdot \frac{dr^r}{dt} - \omega_D^2 \cdot r^r = 0, \tag{15}$$

having the solution:

$$r_h^r = C_1 \cdot y_1(t) + C_2 \cdot y_2(t) = C_1(t) \cdot e^{\omega_\mathrm{D}(-\mu_V + \sqrt{1+\mu_V^2}) \cdot t} + C_2(t) \cdot e^{\omega_\mathrm{D}(-\mu_V - \sqrt{1+\mu_V^2}) \cdot t} \tag{16}$$

where C_1 and C_2 are the unknown integration constants.

A particular solution of the inhomogeneous differential equation (13) can be found by the method of an undetermined constant:

$$r_p^r = C. \tag{17}$$

After differentiation of the equation (17) and inclusion in the equation (13), the particular solution of the inhomogeneous differential equation arose:

$$r_p^r = \frac{\mu_D \cdot g}{\omega_D^2}, \tag{18}$$

giving the general solution of the differential equation (13), which describes the *relative* radial position of the fertilizer particle:

$$r^r(t) = C_1 \cdot e^{\omega_D \cdot \left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot t} + C_2 \cdot e^{\omega_D \cdot \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot t} + \frac{\mu_D \cdot g}{\omega_D^2}. \tag{19}$$

The derivation of this equation gave the relative radial velocity of the particle:

$$\begin{aligned} \dot{r}^r(t) = v^r(t) = \omega_D \cdot \left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot C_1 \cdot e^{\omega_D \cdot \left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot t} + \\ + \omega_D \cdot \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot C_2 \cdot e^{\omega_D \cdot \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot t} \end{aligned}. \tag{20}$$

The integration constants C_1 and C_2 were determined from the initial conditions, which arose from the design and operational conditions of the analyzed fertilizer disc spreader:

$$t_0 = 0 \implies r^r(t_0 = 0) = r^r(0) = R_0, \tag{21}$$

$$t_0 = 0 \implies \dot{r}^r(t_0 = 0) = \dot{r}^r(0) = \dot{r_0}^r = {v_0}^r = 0. \tag{22}$$

Namely, each fertilizer particle starts the relative motion along the vane from its inner edge and accelerates starting from the zero radial velocity. Combining the formulas (19), (20), (21) and (22) gave the constants C_1 and C_2. Their introducing in equations (19) and (20) provided the final expressions defining the relative position and velocity of the particle along the vane:

$$\begin{aligned} r^r(t) = \frac{\left(R_0 - \frac{\mu_D \cdot g}{\omega_D^2}\right)}{2 \cdot \sqrt{1+\mu_V^2}} \cdot \left[\left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot e^{\omega_D \cdot \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot t} - \right. \\ \left. - \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot e^{\omega_D \cdot \left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot t} \right] + \frac{\mu_D \cdot g}{{\omega_D}^2}, \end{aligned} \tag{23}$$

$$\begin{aligned} \dot{r}^r(t) = v^r(t) = \\ \frac{-\omega_D}{2 \cdot \sqrt{1+\mu_V^2}} \cdot \left(R_0 - \frac{\mu_D \cdot g}{\omega_D^2}\right) \cdot \left[e^{-\omega_D \cdot \left(\mu_V + \sqrt{1+\mu_V^2}\right) \cdot t} - e^{-\omega_D \cdot \left(\mu_V - \sqrt{1+\mu_V^2}\right) \cdot t} \right]. \end{aligned} \tag{24}$$

The fertilizer particle ejection (launching) time t_K represents the traveling time of a fertilizer particle along the whole length of a centrifugal disk spreader vane, $r^r(t_K) = R_1$:

$$\begin{aligned} r^r(t_K) = R_1 = \frac{\left(R_0 - \frac{\mu_D \cdot g}{\omega_D^2}\right)}{2 \cdot \sqrt{1+\mu_V^2}} \cdot \left[\left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot e^{\omega_D \cdot \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot t_K} - \right. \\ \left. - \left(-\mu_V - \sqrt{1+\mu_V^2}\right) \cdot e^{\omega_D \cdot \left(-\mu_V + \sqrt{1+\mu_V^2}\right) \cdot t_K} \right] + \frac{\mu_D \cdot g}{{\omega_D}^2}. \end{aligned} \tag{25}$$

The absolute velocity vector $\overrightarrow{v^a}$ of the particle is a vector sum of the carrying velocity $\overrightarrow{v^c}$, induced by vane and disc spinning, and the relative velocity along the vane $\overrightarrow{v^r}$ (Figure 4):

$$\overrightarrow{v^a}(t) = \overrightarrow{v^c}(t) + \overrightarrow{v^r}(t). \tag{26}$$

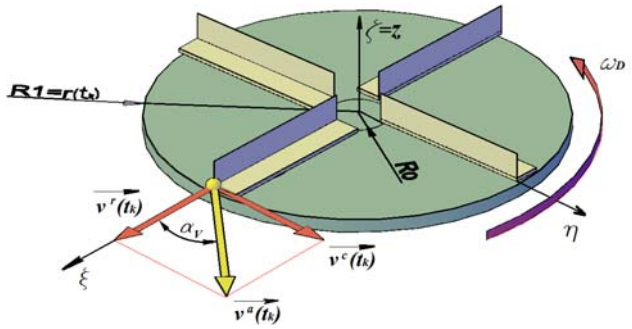

Figure 4. Components of the absolute velocity vector of the fertilizer particle.

The relative velocity vector is aligned with the positive direction of the $O\xi$ axis and the carrying velocity is aligned with the positive orientation of the axis $O\eta$. The magnitude of the relative velocity, as a function of time, is defined by the formula (24). Thus, its magnitude at the particle ejection point can be calculated by substituting $t = t_K$ in the equation (24):

$$v^r(t_K) = \frac{-\omega_D}{2\cdot\sqrt{1+\mu_V^2}} \cdot \left(R_0 - \frac{\mu_D \cdot g}{\omega_D^2}\right) \cdot \left[e^{-\omega_D \cdot \left(\mu_V + \sqrt{1+\mu_V^2}\right)\cdot t_K} - e^{-\omega_D \cdot \left(\mu_V - \sqrt{1+\mu_V^2}\right)\cdot t_K}\right], \tag{27}$$

where the ejection time t_K is defined by the formula (25).

The magnitude v^c of the carrying velocity $\overrightarrow{v^c}$ vector is the multiple of the particle radius r^r and the angular velocity $\omega_\mathrm{D} = const.$ of a carrying motion (spreading disc rotation):

$$v^c(t) = r^r(t) \cdot \omega_\mathrm{D}. \tag{28}$$

At the ejection point, a fertilizer particle reaches the outer disc radius $r^r(t_K) = R_1$. Therefore, at the ejection point, the magnitude v^c of the carrying velocity has the value:

$$v^c(t_k) = R_1 \cdot \omega_\mathrm{D}. \tag{29}$$

Therefore, the magnitude of the absolute velocity vector (Figure 4) was evaluated using the well-known Pythagoras theorem:

$$v^a(t) = \sqrt{[v^c(t)]^2 + [v^r(t)]^2} \Longrightarrow v^a(t_k) = \sqrt{[v^c(t_k)]^2 + [v^r(t_k)]^2}. \quad (30), (31)$$

Its orientation is defined by the polar angle (Figure 4):

$$\tan\{\alpha_v(t)\} = \frac{v^c(t)}{v^r(t)} \Longrightarrow \tan\{\alpha_v(t_k)\} = \frac{v^c(t_k)}{v^r(t_k)}; \quad (32), (33)$$

$$\alpha_v(t) = \arctan\left\{\frac{v^c(t)}{v^r(t)}\right\}[rad] = \frac{360}{2 \cdot \pi} \cdot \arctan\left\{\frac{v^c(t)}{v^r(t)}\right\}[°]; \quad (34)$$

$$\alpha_v(t_k) = \arctan\left\{\frac{v^c(t_k)}{v^r(t_k)}\right\}[rad] = \frac{360}{2 \cdot \pi} \cdot \arctan\left\{\frac{v^c(t_k)}{v^r(t_k)}\right\}[°]. \quad (35)$$

Numerical results

All calculations, based on the presented analytical model, were performed using MS EXCEL and the input data given in Table 1.

Table 1. Input data for the analytical model.

n [min^{-1}]	R_0 [m]	R_1 [m]	μ_D [-]	μ_V [-]	g [m·s^{-2}]
300	0.045	0.21	0.3	0.4	9.81

The radial position of the sliding fertilizer particle $r^r = r^r(t)$ was calculated using the expression (23), as it is illustrated in Figure 5a. The total particle traveling time t_K, along the vane, is defined by the formula (25) that cannot be solved analytically. Therefore, its solution was found numerically, using MS EXCEL and the "sweeping method" applied to the equation (25) and the border condition $r^r(t_K) = R_1$, $t_k = 0{,}0927\ [s]$.

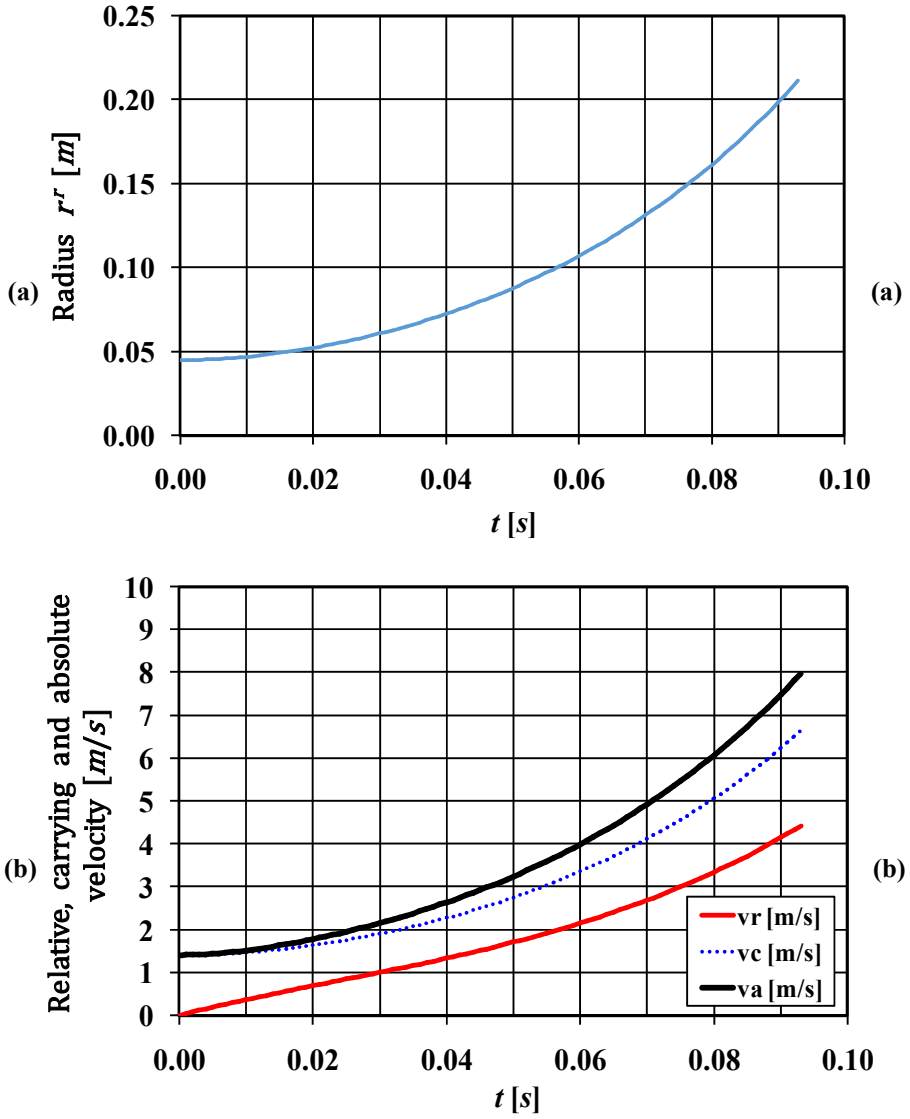

Figure 5. Kinematic parameters of the fertilizer particle motion along the vane, with respect to traveling time: (a) radial position $r^r(t)$; (b) —— relative $v^r(t)$,·····carrying $v^c(t)$ and —— absolute velocity $v^a(t)$.

Numerical values defining the fertilizer particle velocity vector, including their values at the launching point, were found using expressions (24), (27), (28), (29), (30), (31), (34) and (35), and presented in Figures 5b and 6.

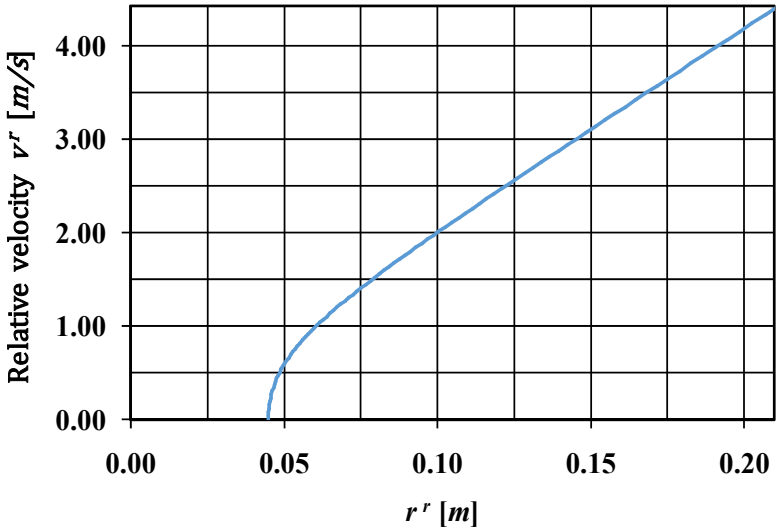

Figure 6. The radial velocity of the fertilizer particle along the radial vane, with respect to its distance from the spinning axis.

As can be seen from the charts presented in Figures 5 and 6, the launching value of the absolute velocity vector magnitude (at the ejecting point) is

$$v^a(t_k) = 7{,}93 \left[\frac{m}{s}\right],$$

and its angle toward the radial vane (for an illustration, see Figure 4) is:

$$\alpha_v(t_k) = 56{,}35\ [°].$$

Conclusion

The dynamic model for evaluation of the ejection velocity vector of the fertilizer particle from the spinning disc of a centrifugal spreader, having the flat disk with straight radial vanes, is presented in the paper. This work will be continued in order to develop a ballistic model of the fertilizer particle flight, which is expected to enable the prediction of the landing distance and the fertilizer spreading pattern.

The influence of the inclination vane angle toward the spinning disc (inclined forward, inclined backward or orthogonal to a disk) has not been completely resolved yet, especially when combined with the influence of a friction coefficient. This phenomenon should be also included in the more advanced future models of solid fertilizer spreading by disk spreaders.

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KRETANJE ČESTICE ĐUBRIVA DUŽ LOPATICE CENTRIFUGALNOG RASIPAČA SA DISKOM PRETPOSTAVLJAJUĆI ČISTO KLIZANJE ČESTICE

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R e z i m e

U Evropi se za rasipanje granularnog mineralnog đubriva najčešće koriste centrifugalni rasipači sa lopaticama. U ovom radu je analizirano kretanje idealne, loptaste, homogene granule đubriva duž lopatica postavljenih po rotirajućem disku. Analiza je izvedena primenom neinercijalnog referentnog koordinatnog sistema. Uvođenjem određenih pretpostavki i primenom zakona teorijske mehanike za opisivanje kretanja čestice, formirana je nehomogena diferencijalna jednačina drugog reda sa konstantnim koeficijentima. Njeno rešenje aproksimira realno relativno kretanje čestice đubriva duž ravnih radijalnih lopatica pričvršćenih za horizontalni disk, koji se obrće konstantnom ugaonom brzinom. Dobijeno rešenje se svakako može koristiti za optimizaciju radnih parametara centrifugalnog rasipača sa diskom.

Ključne reči: granula đubriva, centrifugalni rasipač sa diskom, radijalne lopatice, diferencijalna jednačina.

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EFFECT OF SOCIAL CAPITAL ON PRODUCTIVITY OF CASSAVA FARMERS IN OGUN STATE, NIGERIA

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Abstract: Nigeria is an agriculturally labor-intensive economy and the protection and utilization of the labor resource to guarantee the highest productivity are of immense vitality to the growth of the agricultural sector. This study assessed the relationship between the social capital and the productivity of cassava farmers in Ijebu North-East Local Government Area of Ogun State. A purposive sampling procedure was employed in the study. Data were collected from one hundred and thirty-nine cassava farmers by the use of a well-structured questionnaire. Data were analyzed using descriptive statistics, total factor productivity and ordinary least squares model. The mean age and household size of cassava farmers were 44.2±9.9 years and 6.0±3.1 respectively. The density of memberships in associations was 2.7±1.3. The average meeting attendance index by farmer was three out of four meetings (77.2%). The association membership was moderately diversified with a heterogeneity index of 59.2% and farmers participated in one out of four decision making processes of their associations. A monthly cash contribution of farmers to associations was low (₦132.04±₦107.67) and the trust index was 0.296. Farmers cultivated an average of 1.25 ha with total factor productivity of 0.096kg/₦. Results show that age of the farmer, age squared (life cycle), household size, farm size, cash contribution and decision making significantly determined the productivity of cassava farmers in the study area. Social capital variables significantly influenced cassava farmers' productivity. It is therefore suggested that policy makers interested in farmers' production output should make active participation in local level institutions compulsory.

Key words: social capital, productivity, agricultural sector, cassava farmers, Nigeria.

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Introduction

The Nigerian agricultural sector contributes about 35% of Gross Domestic Product (GDP) of the economy and it employs over 70% of the population (Oxfam, 2007). Notwithstanding rapid levels of the rural-urban movement, poor rural inhabitants still account for about half of the Nigerian populace (ESA/UN, 2009; Akinbami and Fadare, 1997). This sector is still dominated by small-scale farmers accounting for over 90% of the total output of food crops, especially roots and tubers, for example cassava (IFAD, 2006).

Cassava (*Manihot esculenta*) is a staple food of most households in Nigeria and other developing countries. It is a critical factor in poverty alleviation and cultivation, processing and marketing of the crop provide employment opportunities for the rural and urban population. According to Nweke et al. (2002), the crop has the potential for bridging the food gap and famine rarely occurs where cassava is widely cultivated. Cassava farming is mainly practiced by small-scale farmers and their production is mainly characterized by low productivity.

A low agricultural output in Nigeria is due to an array of factors such as poor soil management practices, the adverse impact of climate change on the environment, non-availability and high cost of inputs, crude farm tools, and obsolete farming practices. The persistent welfare loss and food insecurity, as a result of the poor agricultural output, account for 70 percent of Nigerians who are food insecure (Orewa and Iyangbe, 2009). According to Akpabio (2008), small-scale farmers in Africa have remained the central focus of development efforts based on the belief that policies targeting at them will positively impact on their food production efforts and poverty reduction.

Despite efforts made by various past governments in Nigeria and aimed at improving agricultural productivity and efficiency of the rural farmers who are the major participants of agricultural production, the country is still food insecure (Simonyan, Olukosi and Omolehin, 2010). One of these efforts is Root and Tuber Expansion Program geared towards increasing root and tuber crop production. In 2002, the Presidential Initiative on Cassava Production and Export was introduced by the Nigerian government aimed at using cassava production as the engine of economic growth for the nation. Also in 2011, the Nigerian government unfolded Agricultural Transformation Agenda (ATA) with a specific goal to increase cassava production in Nigeria to 17 million metric tons from 20 million metric tons targeted for the production of staple food crops between 2011 and 2015 in the country (National Planning Commission, 2011).

The availability of production resources and use of these inputs in the right proportion are necessary to achieve increased output and productivity in Nigerian agriculture (CBN 1999; Balogun, 2011). In order to boost farmers' productivity

and income of farmers, various past governments in Nigeria have been trying to encourage rural farmers in diverse ways to adopt modern production technologies at various levels. Nevertheless, there are some constraints impeding these efforts, for example the inability of rural farmers to secure the necessary collateral to enable access to loans from financial institutions.

Social capital has increasingly gained facets in many aspects of agricultural production and rural development in most developing countries. This has led to perceived positive costs of social capital in development and opening of opportunities to those who lack access to financial, human or natural capital (Meinzen-Dick, DiGregorio and McCarthy, 2004). Rural areas are naturally bestowed with natural capital which includes land and water coupled with adequate human capital which is acquired as a result of years of experience in cassava production and are undermined by the other types of capital such as financial and social capital. These capital resources are therefore converted into physical assets for increased production (World Bank, 2007). To meet the increasing demand of production, farmers need financial assistance but unfortunately they cannot provide collateral required by financial institutions. The farmers are therefore hindered from making any approach to these institutions for credit to improve and increase production. This has given rise to alternative measures of raising financial capital (social networks) in order to transform available natural inputs into physical products. Credit is an essential factor for input acquisition by the rural poor. Credit access and proper usage have also been identified to enhance rural household production output in Nigeria (Okunmadewa, 2001; Okoruwa and Oni, 2002; Balogun, 2011). However, the difficulties created by formal credit sources such as high interest rates and terms for such loans are always discouraging (Balogun, 2011).

Limited accessibility to credit reduces productivity and income of rural small-scale farmers. Obisesan (2013) has revealed that farmers who are members of cooperatives have easier access to credit. Thus, association membership is a synonym for social capital and therefore provides the necessary collateral security that most formal credit institutions demand. Social capital is therefore perceived as a substitute for mobilizing financial capital needed for transforming of natural resources to physical assets and can be accumulated through active participation in local level institution activities (Baron et al., 2000). It has now become pertinent to investigate the effects of social capital on the productivity of cassava farmers in Ijebu North-East Local Government Area of Ogun State, Nigeria. The specific objectives are:

1. to profile the socio-economic characteristics and social capital dimensions of cassava farmers;
2. to determine the total factor productivity of cassava farmers, and
3. to examine the determinants of the productivity of cassava farmers.

Conceptual/theoretical framework and literature review

The term 'social capital' refers to elements like trust, civic spirit, solidarity and readiness to associate, build and maintain communities (Putnam, 1993). Social capital, as defined by Astone and Mclanahan (1991), also refers to the relationship between different family members that determines how individual members can take advantage of whatever financial and human capital other family members possess. Social capital comprises informal forms of institutions and organizations that are based on an emotional attachment to a group, networks, and associations that create shared knowledge, mutual trust, social norms, and unwritten rules (World Bank, 1998; Putnam et al., 1993; Durlauf and Fafchamps, 2005).

The hypothesized relationship between social capital and agricultural productivity is synergetic and interrelated. Social capital impacts agricultural productivity indirectly by affecting the supply of labor, both household and hired, as well as by being a source of information for households. Households process this information to make technology adoption decisions that have direct impacts on their levels of productivity. Social networks may also indirectly influence agricultural productivity by impacting farming practices and household's propensity to adopt new technologies through social networks (Katungi, 2007; Liverpool and Winter-Nelson, 2010). The concept of social capital as an important determinant of economic development is attracting increasing attention among development economists. Social capital in every sense is one of the fundamental factors of development. No country can achieve sustainable economic expansion without substantial investment in human capital. Social capital is an informal norm that promotes cooperation between individuals. Social capital enriches people's understanding of themselves and the world.

Social capital manifested in community-based organizations or in personalized social networks has been found to play an important role in the adoption of crop technologies (Isham, 2002; Katungi, 2007) and production output of banana farmers (Odebode and Adetunji, 2010).

Van den Broeck and Dercon (2007) have analyzed whether agricultural information flows give rise to social learning effects in banana cultivation in Nyakatoke, a small Tanzanian village, using information on socio-economic characteristics and banana farmers' families, neighbours and informal insurance group members. The results have shown that social effects are strongly dependent on the reference group and no effects of social networks are found in distance-based groups and only kinship related groups generate the endogenous social effects that produce positive externalities in banana output.

Materials and Methods

Area of study

The study was conducted in Ijebu North-East Local Government Area (LGA) of Ogun State, Nigeria. The LGA is one of the local governments in Ogun state. This area was chosen because of a high concentration of cassava farmers. The major economic activities of the inhabitants of LGA are farming and trading.

Sampling procedure and size: The primary data employed for this study were gathered using a well-structured questionnaire. One hundred and thirty-nine cassava farmers were purposively selected. Data obtained from these farmers were based on socio-economic/demographic characteristics, local level institution activities, cassava productive activities (input and output), household consumption expenditure and income.

Analytical techniques: The tools employed included descriptive statistics, total factor productivity and regression model.

(i) Descriptive: Descriptive statistics which show the frequency, mean, standard deviation and percentage were used to profile the socio-economic characteristics of the cassava farmers.

(ii) Total factor productivity model: According to Key and McBride (2003), the total factor productivity model was adopted and used. The model was approximated by a linear relationship. The total factor productivity (TFP) was measured as the inverse of the average unit cost of production.

$$\text{TFP} = \frac{Q}{AVC} \text{ or } \frac{1}{AVC} \quad (1)$$

$$\text{TFP} = \frac{Q}{\sum_{i=1}^{n} PX_i X_i} \quad (2)$$

n variable inputs
$\text{TFP} = f(X_1, X_2, X_3, \ldots, X_n)$

where n = Number of variables
$\text{TFP} = \beta_0 + \beta_1 X_1 + \beta_2 X2 + \beta_3 X_3 + \ldots + \beta_{13} X_{13}$

where TFP = Total factor productivity (kg/₦);
X_1 = Gender of household head (male = 0, female = 1);
X_2 = Age (years);
X_3 = Age squared (years) ²;
X_4 = Marital status (married = 1, otherwise = 0);
X_5 = Household size (persons);

X_6 = Farming experience (years);
X_7 = Farm size (hectares);
X_8 = Density of membership (persons);
X_9 = Heterogeneity index (%);
X_{10} = Meeting attendance index (%);
X_{11} = Cash contribution (₦);
X_{12} = Decision making index (%);
X_{13} = Trust index (%);
β_0 = Intercept;
β_i's = Parameters to be estimated, and
μ = Error term.

The explanatory variables used in this study were drawn substantially from the works of Rahman (2007), Key and McBride (2003), Yusuf (2008) and Durojaiye et al. (2014). The selection of the variables for the total factor productivity model in this study was guided by findings in the literature (Rahman 2007; Key and McBride, 2003).

Results and Discussion

The summary statistics of some of the variables included in the regression are shown in Table 1. The results show that the mean age and household size of cassava farmers were 44.2±9.9 years and 6.0±3.1 respectively.

Table 1. Summary statistics of some variables used in the regression.

Variable	Mean	Standard deviation	Minimum	Maximum
Age (year)	44.2	9.92	25	72
Household size	6.0	3.05	1.0	15
Years spent in school (year)	12.05	4.09	0	16
Farm size (ha)	1.25	0.56	0.11	5.0
Membership density	2.67	1.33	1.00	6
Heterogeneity index %	59.21	17.18	4.55	100.0
Meeting attendance index %	77.23	25.06	25.06	100.0
Cash contribution (naira)	132.04	107.67	10.00	1000
Decision making index %	31.75	16.95	11.11	70.11
Trust index	0.296	0.187	0.00	1.0

Farmers cultivated an average of 1.25 ha. The density of memberships in associations was 2.7±1.3. The average meeting attendance index by farmer was three out of four meetings (77.2%). The membership of the association was highly

diversified with the heterogeneity index of 59.2% and farmers participated in one out of four decision making processes of their associations. A monthly cash contribution of farmers to associations was low (₦132.04±₦107.67) and trust index was 0.296.

The socio-economic characteristics and social capital dimensions of cassava farmers are presented in Table 2. The results show that female farmers had the higher heterogeneity index of 60.2%, that is, they were more diversified in the associations they belonged to. Male cassava farmers had a slightly higher average value of meeting attendance in their association meetings in their local association than their female counterparts. The results show that farmers mostly attended two-thirds of their association scheduled meetings because of benefits and opportunities there.

Table 2. Socio-economic characteristics and social capital dimensions of cassava farmers.

	Heterogeneity index %	Meeting attendance index %	Cash contribution (Naira)	Decision making index %	Trust index %	Membership density	Social capital
Gender							
Male	56.5(17.7)	77.3(24.5)	137.9(75.8)	34.2(10.9)	0.297(0.143)	2.9(1.5)	57.3(34.9)
Female	60.2(16.9)	77.2(23.4)	124.9(80.1)	30.8(13.3)	0.296(0.134)	2.6(1.1)	50.7(37.3)
Age (year)							
Less than 30	64.8(3.9)	53.0(11.0)	156.3(65.6)	25.0(20.8)	0.35(0.15)	1.5(0.5)	31.1(32.9)
30−40	56.3(13.9)	80.2(23.8)	137.4(93.7)	30.4(8.8)	0.27(0.13)	3.0(1.1)	51.9(29.2)
41−50	59.4(12.3)	76.7(21.6)	140.0(67.7)	30.7(13.3)	0.31(0.16)	2.5(1.2)	40.1(35.3)
More than 50	62.4(13.3)	76.7(21.9)	110(68.8)	35.9(16.7)	0.32(0.12)	2.5(0.9)	62.1(43.3)
Education level							
No formal	60.6(11.4)	67.6(32.4)	121.1(73.2)	23.3(16.7)	0.30(0.04)	2.8(1.3)	54.3(37.6)
Primary	55.6(19.1)	80.6(23.9)	121.8(71.1)	27.8(8.1)	0.23(0.09)	3.1(1.1)	49.9(29.9)
Secondary	59.4(10.6)	69.1(22.0)	132.6(73.7)	30.3(17.4)	0.33(0.16)	2.3(0.9)	47.1(39.6)
Tertiary	59.7(12.4)	82.7(19.8)	360.0(32.0)	34.1(10.4)	0.29(0.15)	2.8(1.3)	57.1(34.6)
Marital status							
Married	66.5(9.9)	80.9(24.4)	136.3(80.6)	32.5(13.1)	0.29(0.14)	2.8(1.1)	54.6(37.2)
Otherwise	58.1(13.3)	76.7(22.4)	105.0(60.0)	26.9(8.8)	0.29(0.19)	2.1(2.1)	38.5(21.9)

Source: Field survey (2014). Figures in parentheses are standard deviations.

The commitment of male farmers over the female counterparts in their associations is reflected in slightly higher cash contributions and involvement in decision making regarding association matters. The results also show that male cassava farmers had some level of trust than female farmers; however, male farmers had the higher density of membership in associations. Table 2 also shows

that cassava farmers aged less than 30 years and more than 50 years had high percentages of diversity in their social institutions with values of 64.8% and 62.4% respectively. This could be due to the fact that some the farmers were young and not mature enough to take some decisions or too old and already experiencing weakness or reduction in active farming activities. The results related to meeting attendance reveal that members of all age categories with the exception of those aged less than 30 years attended three out of four scheduled meetings of their various associations. However, the highest representation of 80.2% for meeting attendance was recorded for the group of members aged 30−40 years. The highest cash contribution (₦156.30) was recorded for the group of farmers aged under 30 years while the least, ₦110.0, was contributed by farmers aged above 50 years. The reason could be attributed to a reduction in income as age increases or to a reduction in their income generating activities due to health reasons. These results support the findings reported by Adepoju and Oni (2012) that cash contribution to association by household's head declines as age increases. The majority (35.9%) of the farmers aged above 50 years participated in decision making in their associations, while those aged under 30 years participated least (25%). The results reveal that all the age groups participated in less than half of decision making processes in their various associations. The result shows that the highest level of trust was observed in the group of farmers aged less than 30 years and the lowest level was recorded in the group of members aged 30−40 years. Table 2 reveals that the 30−40 age group accounted for the density of membership (3 members) in local level institutions, followed by farmers aged 41−50 years and above 50 years. Those aged under 30 years had the lowest membership density. The overall social capital dimensions show that most cassava farmers (62.1%) were within the age group of 50 years and above and had the highest aggregate social capital. The results indicate that the farmers with no formal education were the most diversified with 60.0% while the least diversified were those with primary education. These results are in line with the findings of Adepoju and Oni (2012) that uneducated households are more diversified than educated ones. Meeting attendance across the educational categories shows that all the farmers had at least 67% meeting attendance. The quest to augument their earnings from other sources might have made attending meetings impossible for them. However, cassava farmers who received tertiary education had the highest value of contribution with an average of ₦360.0 as their monthly contribution to their various associations. Farmers with no formal education accounted for the least cash contribution with ₦121.10 as a cash contribution to their associations. This can be attributed to the fact that these people belong to the least paid group, which will likely reflect in their contribution capability to the local level institution. The results reveal that all the educational level categories claimed to partake in a decision making process in their various associations. Farmers with no formal education had the least average value in the

decision making processes in their associations. It is observed that as an individual farmer became more educated, the extent of involvement in the decision making process in the associations he/she belonged to increased. The highest social values of more than 50% were observed for farmers educated to tertiary level and farmers with no formal education while the values for those with secondary and primary education were lower. Married farmers were more diversified in their respective association than single, divorced or separated farmers. The results show that they had higher values for meeting attendance (80.9%) and contributed more to their local associations in terms of cash (₦136.30) than their single counterparts. The implication is that they would be more committed and would always be ready to do anything to protect their investments in their association. Married cassava farmers contributed more to their local associations in terms of cash (₦136.30) than their single counterparts because their wives were always there for processing and marketing operations required for the output. However, as for decision making, married farmers participated slightly more than single farmers in the decision making process in their association. Regarding their marital status, members trusted one another and membership density was slightly higher in the households of married farmers than in the households of single, divorced or separated farmers. The result reveals that the level of trust in married and single cassava farmers was the same. In all, the married farmers had a higher aggregate social capital than the single in the study area.

The average variable cost and the average quantity of output are depicted in Table 3. The total factor productivity was calculated by dividing average output of cassava produced by farmers by the average variable cost. The results show that the average output of cassava farmers was 15,285.71kg while the average variable cost in naira was ₦158,500.

Table 3. The average variable cost and the average output of cassava farmers.

Variable input	Average quantity	Price/Unit	Total amount (₦)
Planting materials	100 bundles	₦250	₦25000
Total labor used	130 man-days	₦850	₦110,500
Quantity of herbicide	10 liters	₦800	₦8,000
Quantity of organic fertilizer	2 bags/kg	₦7,500	₦15,000
Total cost			₦158,500
Quantity of cassava harvested	15,285.71kg	₦28.0	₦427,999.88
Total factor productivity			0.096kg/₦

Source: Field survey 2015.

The results suggest that for every ₦1 incurred in the cassava production there was approximately 0.096kg of cassava produced.

The results of the determinants of the productivity of cassava farmers are presented in Table 4. The results show that age of the farmer, age squared (life cycle), household size, farm size, cash contribution and decision making significantly determined the productivity of cassava farmers in the study area. The results show that a unit increase in cassava farmer's age increased his/her productivity by 0.448 unit. Age had a quadratic relationship with respect to productivity and it was positive for age and negative for age squared. These results imply that as a cassava farmer advanced in age, his/her productivity decreased. The relationship between the age of a cassava farmer and his/her productivity suggests that the older the farmers, the lower the productivity. An additional age to a farmer decreased his/her productivity by 0.517 unit. Therefore, as a farmer grows older the ability to do rigorous farming activities decreases and negatively affects his/her production output. On the other hand, household size was positive and significantly affected farmer's productivity. A 100% increase in the variable increased production output by 12.9%.

Table 4. Determinants of productivity of cassava farmers.

	Coefficients	Standard error	T value	(P-value)
Constant	9.01892*	4.953384	1.82	0.071
Gender	0.660565	0.5029001	1.31	0.191
Age	0.447859**	0.2026791	2.21	0.027
Age squared	-0.516553*	0.2804118	-1.84	0.065
Marital status	-0.1959962	0.4165314	-0.47	0.639
Household size	0.129611*	0.0776058	1.67	0.097
Farming experience	0.02003	0.0493321	0.41	0.685
Farm size	0.13274***	0.0426845	3.11	0.007
Density of membership	0.3028322	0.1945991	1.56	0.122
Heterogeneity index	0.0033015	0.0133989	0.25	0.806
Meeting attendance index	0.0034193	0.0104	0.33	0.745
Cash contribution	0.00449**	0.0022098	2.03	0.044
Trust index	0.8024189	1.339908	0.60	0.550
Decision making index	0.5803**	0.2291795	2.53	0.013
R^2= 0.2964				
Adj R^2= 0.2238				
F-value= 4.08				
Prob> F= 0.0000				

NB: *Significant at the 10% level, **Significant at the 5% level, ***Significant at the 1% level. Source: Field survey, 2014.

The positive relationship between household size and total factor productivity suggests that a household with a larger family size tended to have higher productivity than those with a small household; this can be related to the amount of

family labor available for farming. The results agree with Atagher (2013) that a large family size leads to an output increase if the members help in the farm. The results indicate that farm size was positive and significantly related to farm productivity. The results further show that a hectare increase in cassava farm increased productivity by 0.133 unit. This is because in a large farm, there are greater opportunities to use modernized tools and skilled laborers that invariably will increase productivity of the farmer. The results indicate there was a positive relationship between a cash contribution of farmers in their local associations and productivity. It therefore suggests that donations, levies, fees and other contributions paid by households in their local institutions went a long way in accessing loans for production and consumption purposes and thereby resulted in increased farm productivity. The results agree with Ajani and Tijani (2009) and Balogun and Yusuf (2011) that a cash contribution to association is presumably a sign of greater interest in the association and serves as a collateral effect for farmers demanding credit from formal credit institutions. However, participation in decision making of the farmers in their various associations reveals that farmers participating in all their association decision making processes increased productivity by 58.0%. This is an indication that farmers who participated actively in decision making in their local level institutions were better positioned to enjoy the benefits coming to their association concerning how to run the farm efficiently.

Conclusion

The study focuses on the effect of social capital on the productivity of cassava farmers in Ijebu North-East Local Government Area of Ogun State, Nigeria. The study reveals that the average age of a cassava farmer in the area was 44.2 years. Household size was 6 members. The results have shown that most cassava farmers had large family sizes. However, farmers in the study area cultivated an average area of 1.25 ha. This study further reveals that the average total factor productivity of the cassava farmers in the study area was 0.096kg/₦. The study further shows that socio-economic, farm specific and social capital variables (age, age squared, household size, meeting attendance, farm size, cash contribution, decision making index) significantly influenced cassava farmers' productivity. The results of this study have revealed that there was a need for more investment in social networks in order to improve productivity of farmers and boost cassava production. Based on the findings of this study, the following recommendations have been made to improve cassava farmers' productivity in Ogun State. It is therefore suggested that policy makers interested in improving the living conditions of farmers and their production output should encourage them to increase their participation in their association activities. Farmers should be encouraged to join associations to be able to benefit from programs and training targeted at improving food production in the country.

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UTICAJ SOCIJALNOG KAPITALA NA PRODUKTIVNOST PROIZVOĐAČA MANIOKE U DRŽAVI OGUN, NIGERIJA

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R e z i m e

Nigerija je poljoprivredno radno-intenzivna privreda, te zaštita i korišćenje resursa rada koji garantuju najvišu produktivnost su od vitalnog značaja za rast poljoprivrednog sektora. Ovim istraživanjem je procenjivan odnos između socijalnog kapitala i produktivnosti poljoprivrednih proizvođača manioke u severoistočnoj oblasti lokalne uprave Ijebu u državi Ogun. U istraživanju je korišćen ciljani postupak uzorkovanja. Podaci su prikupljeni od sto trideset i devet poljoprivrednih proizvođača manioke uz pomoć dobro strukturiranog upitnika. Podaci su analizirani korišćenjem deskriptivne statistike, ukupne faktorske produktivnosti i običnog modela najmanjih kvadrata. Prosečna starost i veličina domaćinstava poljoprivrednih proizvođača manioke bili su 44,2±9,9 godina odnosno 6,0±3,1. Gustina članstva u udruženjima iznosila je 2,7±1,3. Prosečan indeks prisutnosti sastancima po poljoprivrednom proizvođaču bio je tri od četiri sastanka (77,2%). Članstvo u udruženju bilo je umereno diversifikovano sa indeksom heterogenosti od 59,2%, a poljoprivredni proizvođači su učestvovali u jednom od četiri procesa odlučivanja svojih udruženja. Mesečni gotovinski doprinos poljoprivrednih proizvođača udruženjima bio je nizak (₦132,04±₦107,67), a indeks poverenja iznosio je 0,296. Poljoprivredni proizvođači su obrađivali u proseku 1,25 ha sa ukupnom faktorskom produktivnošću od 0,096kg/₦. Rezultati pokazuju da starost poljoprivrednog proizvođača, kvadrat godina starosti (životni ciklus), veličina domaćinstva, veličina gazdinstva, gotovinski doprinos i odlučivanje značajno određuju produktivnost poljoprivrednih proizvođača u ispitivanoj oblasti. Promenljive socijalnog kapitala značajno su uticale na produktivnost poljoprivrednih proizvođača manioke. Stoga se predlaže da bi kreatori politike zainteresovani za proizvodnju poljoprivrednih proizvođača trebalo da aktivno učestvovanje u radu institucija lokalnog nivoa učine obaveznim.

Ključne reči: socijalni kapital, produktivnost, poljoprivredni sektor, poljoprivredni proizvođači manioke, Nigerija.

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Materijal i metode treba izložiti jasno uz objašnjenje svih primenjenih postupaka u radu. Opšte poznate metode izložiti kratko, a detaljnije ih objasniti ukoliko se odstupa od ranije objavljenih postupaka. Za radove eksperimentalnog karaktera obavezno navesti način statističke obrade podataka. U ovom poglavlju, kao i u poglavlju „Rezultati i diskusija“, po potrebi se mogu dati i određena podpoglavlja.

Rezultati i diskusija
U poglavlju „Rezultati i diskusija“ interpretiraju se podaci dobijeni na osnovu zapažanja i izvršenih eksperimenata. U komentaru rezultata treba se pozivati na literaturu koja se navodi na kraju rada, čime se obezbeđuje poređenje dobijenih rezultata sa dosadašnjim saznanjima u toj oblasti.

Zaključak
U zaključku treba ukratko navesti najznačajnije rezultate dobijene u radu. Izbegavati nabrajanje svih rezultata istraživanja sa ponavljanjem brojčanih vrednosti koje su prethodno već navedene u poglavlju „Rezultati i diskusija“. Zaključak ne sme da sadrži reference.

Zahvalnica
Zahvalnica treba da sadrži naziv i broj projekta, odnosno naziv programa u okviru koga je rad nastao, kao i naziv institucije koja je finansirala projekat ili program.

Literatura
Poglavlje „Literatura“ treba da sadrži samo radove citirane u glavnom tekstu. Rad citiran u tekstu treba da sadrži prezime autora i godinu. Ako citat obuhvata jednog autora on se navodi kao Jalikop (2010) ili (Jalikop, 2010). Kada citat obuhvata dva autora on se navodi kao Sadras i Soar (2009) ili (Sadras i Soar, 2009). Ako se u tekstu citiraju više od dva autora posle prezimena prvog autora navodi se skraćenica „et al.“, a zatim godina. Ovakav citat navodi se kao Lehrer et al. (2008) ili (Lehrer et al., 2008). Ako se za određeni problem istovremeno citira više radova onda se oni hronološki nabrajaju. Odvajanje većeg broja citiranih radova van zagrade vrši se zarezom (,) a u zagradi tačkom i zarezom (;). Ako se citiraju dva ili više rada istog autora oni moraju biti poređani prema hronološkom redu (1997, 2002, 2006, itd.). Ukoliko se određeni autor pojavljuje nekoliko puta u istoj godini, dodaju se slova (2005a, b, c, itd.). Citate ličnih komunikacija i neobjavljenih podataka treba izbegavati, osim ako je to apsolutno neophodno. Takvi citati bi trebali da se pojave samo u tekstu (npr. Brown, lična komunikacija), ali ne i u spisku referenci.

Literatura koja je citirana u tekstu navodi se u spisku referenci u originalnom obliku, po abecednom redu, bez numeracije. Ako se citira veći broj radova istog autora najpre se navode radovi kada je autor sam, a zatim kada su prisutna dva i više autora. Ako se u nekoj od ovih kategorija javlja veći broj radova, treba ih hronološki srediti po godinama (1997, 2002, 2006, itd.), a ako se u istoj godini javlja veći broj radova dodaju se slova (2005a, 2005b, 2005c, itd.). Literaturni podatak treba da sadrži: prezime autora, početno slovo imena, godinu izdanja u zagradi, naslov rada, naziv časopisa, volumen i broj stranica (prva-poslednja). Prilikom citiranja knjiga navodi se izdavač i mesto izdavanja. Redovi svake reference posle prvog reda moraju biti uvučeni. U časopisu se koristi APA - Publication Manual of the American Psychological Association citatni stil.

Primeri navođenja referenci su sledeći:

Periodičan časopis
Gvozdenović, S., Saftić Panković, D., Jocić, S., & Radić, V. (2009). Correlation between heterosis and genetic distance based on SSR markers in sunflower (Helianthus annuus L.). *Journal of Agricultural Sciences*, *54*, 1-10.

Knjiga
Steel, R.G.D., & Torrie, J.H. (1980). *Principles and procedures of statistics*. New York: McGraw-Hill Book Company.

Poglavlje u knjizi
Bell, R.L., Quamme, H.A., Layne, R.E.C., & Skirvin, R.M. (1996). Pears. In J. Janick & J.N. Moore (Eds.), *Fruit breeding, Volume I: Tree and tropical fruits.* (pp. 441-514). New York: John Wiley and Sons, Inc.

Zbornik
Behera, T.K., Staub, J.E., Behera, S., Rao, A.R., & Mason, S. (2008). One cycle of phenotypic selection combined with marker assisted selection for improving yield and quality in cucumber. In M. Pitrat (Ed.), *Proceedings of the IXth EUCARPIA meeting on genetics and breeding of Cucurbitaceae* (pp. 115-121). Avignon.

Teza
Singh, N.K. (1985). *The structure and genetic control of endosperm proteins in wheat and rye*. University of Adelaide.

Izveštaj
Ballard, J. (1998). *Some significant apple breeding stations around the world*. Selah, Washington.

Veb sajt
Platnick, N.I. (2010). The world spider catalog, version 10.5. *American Museum of Natural History*. Retrieved February 12, 2016, from http://research.amnh.org/entomology/spiders/catalog/index.html

Rezime
Rezime na srpskom jeziku (za radove napisane na engleskom jeziku) ili na engleskom jeziku (za radove napisane na srpskom jeziku) navodi se na kraju rada i treba da ima od 100 do 250 reči. Ispred osnovnog teksta rezimea, navodi se naslov rada, puno ime, srednje slovo i prezime svih autora i naziv i adresa ustanove autora. Naslov „Rezime“ piše se razmaknuto i centrirano. Nakon naslova sledi jedan razmak, a zatim tekst rezimea, uvučen jednim tabulatorom. Neposredno nakon teksta rezimea, navode se ključne reči, sa tačkom na kraju. E-mail adresa autora za kontakt navodi se ispod crte, pri dnu stranice.

Tabele
Tabele obeležene arapskim brojevima (1, 2, itd.) praćene naslovom treba da se nalaze na odgovarajućem mestu u tekstu, u fontu 9. Maksimalna širina tabela treba da bude 13 cm. One treba da budu jasne, što jednostavnije i pregledne. Treba izbegavati vertikalne crte, a broj kolona ograničiti tako da tabela ne bi bila preširoka. Takođe, treba izbegavati nepotrebnu upotrebu horizontalnih crta. Naslov tabele, poravnat po levoj i desnoj margini, sa tačkom na kraju, navodi se sa jednim razmakom iznad tabele. Ispod tabele treba dati detaljno objašnjenje skraćenica, simbola i znakova korišćenih u samoj tabeli. Svaka tabela mora biti pomenuta u tekstu.

Ilustracije
Svi grafikoni, dijagrami i fotografije treba da se nazovu „Slika“ (1, 2, itd.). Prilažu se na odgovarajućem mestu u tekstu. Grafikone i dijagrame treba uraditi fontom 9, u crno-beloj tehnici i sa maksimalnom širinom od 13 cm. Voditi računa da oni budu čitki i jasni i nakon redukcije veličine. Za svaki grafikon i dijagram treba obezbediti detaljnu legendu bez skraćenica. Fotografije moraju biti visokog kvaliteta da bi se tehnički mogle dobro reprodukovati. Prilažu se u „TIF“ ili „JPG“ formatu, u crno-beloj tehnici. Naslov ilustracije, poravnat po levoj i desnoj margini, sa tačkom na kraju, navodi se sa jednim razmakom ispod ilustracije. Svaka ilustracija mora biti pomenuta u tekstu.

Skraćenice i jedinice
U radu treba koristiti samo standardne skraćenice. Merne jedinice treba izražavati u internacionalnom sistemu jedinica (SI). Kod navođenja jedinica posle broja treba da stoji razmak (osim za % i °C). Skraćenice se mogu koristiti i za druge izraze pod uslovom da se ti izrazi navedu u punom obliku prilikom prvog pominjanja, sa skraćenim oblikom u zagradi. Vrednosti od 1 do 9 mogu se izražavati slovima, a ostali brojevi isključivo numerički.

Nomenklatura
Celokupna nomenklatura (hemijska i biohemijska, taksonomska, genetička itd.) mora biti usklađena sa međunarodnim kodeksima i komisijama, kao što su *International Union of Pure and Applied Chemistry, IUPAC-IUB Combined Commission on Biochemical Nomenclature, Enzyme Nomenclature, International Code of Botanical Nomenclature, International Code of Nomenclature of Bacteria* itd.

Formule
Sve formule i jednačine u radu moraju biti urađene pomoću programa „Word Equation“. Pri pisanju formula, radi preglednosti, ostaviti dovoljno praznog prostora oko same formule. Subskripti i superskripti treba da budu jasni. Prilikom pisanja jednačina treba dati smisao svih simbola odmah posle jednačine u kojoj se simbol prvi put koristi. Jednačine treba da budu numerisane arapskim brojevima, serijski u zagradama, na desnoj strani linije. Svaka jednačina mora biti pomenuta u tekstu kao Eq. (1), Eq. (2), itd.

Nakon objavljivanja rada, autoru za kontakt će biti poslat jedan primerak časopisa.
Mole se svi budući saradnici da rad pripreme prema datom uputstvu, kako bi olakšali rad redakcije časopisa. Ukoliko se rad ne pripremi po navedenom uputstvu neće biti prihvaćen za objavljivanje.

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