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UTICAJ VREMENSKIH USLOVA, TIPA ZEMLJIŠTA I GUSTINE SETVE NA PRODUKTIVNOST KUKURUZA

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Rezime: Visoki prinosi kukuruza mogu se ostvariti samo na plodnim, rastresitim i dobro propusnim zemljištima. Takođe, dosadašnja istraživanja ukazuju da noviji tipovi hibrida kukuruza povoljno reaguju na povećanje gustine useva. Cilj ovog rada bio je da se prouči uticaj meteoroloških uslova tokom vegetacionog perioda, tipa zemljišta i gustine setve na dužinu klipa, broj redova zrna na klipu, broj sterilnih biljaka, prinos zrna i sadržaj vode u zrnu hibrida kukuruza AS 6E02 (FAO 620). Ispitivanja su obavljena tokom 2017. i 2018. godine putem poljskih mikroogleda u agroekološkim uslovima Vranja metodom razdeljenih parcela (engl. *split-plot*) u četiri ponavljanja na zemljištima tipa gajnjača, smonica i aluvijum. Površina obračunske parcelice za prinos zrna iznosila je 8,4 m^2. Primenjena agrotehnika na ogledima bila je standardna, kao za redovnu proizvodnju kukuruza. Godine u kojima su obavljena istraživanja razlikovale su se u pogledu meteoroloških uslova, količine i rasporeda padavina. U proseku za tipove zemljišta i godine, najmanja dužina klipa (17,6 cm) izmerena je u najređoj setvi. Broj redova zrna nije značajno varirao u zavisnosti od gustine setve. U dvogodišnjem proseku, na prinos zrna jači uticaj je ispoljio tip zemljišta u odnosu na gustinu setve. U proseku za tipove zemljišta i godine, najmanji procenat sterilnih biljaka (1,90%) konstatovan je pri najgušćoj setvi (75.187 biljaka po ha). U 2018. godini izmeren je veći sadržaj vode u zrnu za 8,5 indeksnih poena u odnosu na 2017. godinu.

Ključne reči: kukuruz, zemljište, setva, produktivnost, prinos zrna.

Uvod

Kukuruz (*Zea mays* L.) je biljna vrsta koja je odigrala značajnu ulogu u opstanku i razvoju čovečanstva. Osnovni privredni značaj kukuruza proizilazi iz njegove raznovrsne upotrebe u ishrani ljudi, domaćih životinja i kao sirovina u industrijskoj preradi. U Srbiji, prema podacima Republičkog zavoda za statistiku

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(2023), u 2022. godini kukuruz je požnjeven sa površine od 952.216 ha, sa ukupnom proizvodnjom od 4.283.293 t, odnosno sa prinosom od 4,5 t/ha. Takođe, u odnosu na desetogodišnji prosek (2011–2020), kukuruz je imao manju proizvodnju za 0,7%.

Variranje prinosa kukuruza u našoj zemlji uzrokovano je brojnim organizaciono- ekonomskim, ali i agrotehničkim razlozima. U Srbiji oko 60% površina pod kukuruzom nalazi se na zemljištima manje pogodnim za njegovu proizvodnju, pa je to jedan od glavnih razloga što se ostvaruju niži prinosi (Videnović et al., 2004). Visoki prinosi kukuruza mogu se ostvariti samo na plodnim, rastresitim i dobro propusnim zemljištima. Plodna zemljišta dobro su aerisana i imaju dovoljno lakopristupačnih hranljivih materija. Takve osobine poseduju černozem, smonica, gajnjače i aluvijalna zemljišta. Suprotno tome, teška i zbijena zemljišta, sa visokim nivoom podzemnih voda, kisele pH reakcije i niske mikrobiološke aktivnosti, kao što je pseudoglej, nepovoljna su za proizvodnju kukuruza. Na takvom zemljištu korenov sistem se formira plitko, što se nepovoljno odražava na ishranu i prinos zrna. S druge strane, takođe važan faktor u proizvodnji kukuruza je gustina setve, odnosno useva. Rezultati savremenih istraživanja u svetu i kod nas pokazuju da noviji tipovi hibrida kukuruza povoljno reaguju na povećanje gustine useva (Farnham, 2001).

Cilj ovog rada bio je da se prouči uticaj meteoroloških uslova tokom vegetacionog perioda, tipa zemljišta i gustine setve na važnije parametre produktivnosti i prinos zrna hibrida kukuruza AS 6E02 (FAO 620). Na osnovu dobijenih rezultata i njihove analize utvrdila bi se optimalna gustina setve ispitivanog hibrida kukuruza za agroekološke uslove Vranja, na zemljištu tipa gajnjača, smonica i aluvijum.

Materijal i metode

Ispitivanje uticaja vremenskih uslova, tipa zemljišta i gustine setve na produktivnost kukuruza obavljeno je tokom 2017. i 2018. u Vranju. Poljski mikroogledi su postavljeni na tri tipa zemljišta (gajnjača, smonica i aluvijum). Poljski ogledi izvedeni su metodom razdeljenih parcela (engl. *split-plot*), u četiri ponavljanja. Površina obračunske parcelice za prinos zrna iznosila je 8,4 m^2. Istraživanje je obuhvatilo tri faktora:

Eksperiment je postavljen prema potpuno randomizovanom trofaktorijalnom dizajnu razdeljenih parcela u četiri ponavljanja sa sledećim faktorima:

1. Godina (A): a_1 – 2017, a_2 – 2018;
2. Tip zemljišta (B): b_1 – gajnjača, b_2 – smonica, b_3 – aluvijum;
3. Gustina setve (C): c_1 – 64.935 biljaka po ha (70 x 22 cm), c_2 – 68.027 biljaka po ha (70 x 21 cm), c_3 – 75.187 biljaka po ha (70 x 19 cm).

Faktorske kombinacije a_ib_j su primenjene na glavnim parcelama i unutar njih (na potparcelama), nivoi faktora c_k su nasumično raspoređeni. Statistička analiza je izvršena korišćenjem softvera SPSS 26.0 (SPSS, Inc., Chicago, IL).

Primenjena agrotehnika na ogledima bila je standardna, kao za redovnu proizvodnju kukuruza. Predusev kukuruzu je bila ozima pšenica. Posle žetve pšenice obavljeno je zaoravanje strništa na dubinu 10–15 cm. Osnovno đubrenje je obavljeno mineralnim đubrivom formulacije NPK 15:15:15 u količini od 300 kg/ha, startno đubrivom UREA (46% N) u količini od 200 kg/ha i korektivno KAN-om u količini od 130 kg/ha. Osnovna obrada zemljišta izvedena je tokom jeseni, na dubinu oko 30 cm. Tokom proleća izvršena je dopunska obrada zemljišta i predsetvena priprema zemljišta. Setva je obavljena mašinski, prema planu setve, na dubini od 5–6 cm, na međurednom rastojanju od 70 cm i na odstojanju od 22, 21 i 19 cm, zavisno od planirane gustine setve. U sklopu mera nega korišćeni su odgovarajući herbicidi za suzbijanje korova i međuredna kultivacija. Žetva (berba) je obavljena ručno u fiziološkoj zrelosti semena, krajem septembra, a pre izračunavanja prinosa po hektaru utvrđen je sadržaj vode u zrnu hibrida kukuruza, statičnim vlagomerom. Osim toga, na uzorku od 10 biljaka, odnosno na 14,28 m dužine, iz svih varijanti i iz svih ponavljanja analizirane su sledeće osobine: dužina klipa, broj redova zrna na klipu, broj sterilnih biljaka, prinos zrna i sadržaj vode u zrnu kukuruza.

Prinos zrna sa 14% vode izračunat je po sledećoj formuli: QV = Pi (100-U)/100-US, gde je:

QV – prinos suvog zrna kukuruza, sa 14% vode;

Pi – prinos sirovog zrna;

U – sadržaj vlage u zrnu na dan berbe;

US – dozvoljena vlažnost zrna (14%).

Produktivnost hibrida kukuruza AS 6E02 ispitivana je na gajnjači, smonici i aluvijumu. Na osnovu rezultata agrohemijskih analiza (tabela 1), može se zaključiti da je reakcija zemljišnog rastvora u gajnjače i smonice kisela, a u aluvijumu neutralna.

Tabela 1. Agrohemijske osobine ispitivanih tipova zemljišta (Vranje).
Table 1. Agrochemical characteristics of the examined soil types (Vranje).

Tip zemljišta Soil type	pH n/1 KCl	Humus (%)	N (%)	P_2O_5 mg u/in 100 g zemljišta/soil	K_2O mg u/in 100 g zemljišta/soil
Gajnjača Eutric cambisol	4,35	2,80	0,14	8,0	9,0
Smonica Vertisol	4,82	2,91	0,15	9,2	10,2
Aluvijum Alluvium	6,83	2,25	0,11	11,2	12,3

Humusom su sva tri tipa zemljišta slabo obezbeđena, a ukupnim azotom su dobro obezbeđena. Lakopristupačnim fosforom u gajnjače i smonice je prisutna niska, a u aluvijumu srednja obezbeđenost. Kalijumom su smonica i aluvijum srednje obezbeđeni, a gajnjača ima nizak nivo obezbeđenosti ovim makroelementom.

Vremenski uslovi. Srednje mesečne temperature vazduha u godinama ispitivanja, kao i višegodišnji prosek (2007–2016. godine) u vegetacionom periodu kukuruza, prikazane su u tabeli 2. U obe godine istraživanja, na oba lokaliteta, srednja mesečna temperatura vazduha raste od aprila do avgusta, a zatim se smanjuje. Prosečna temperatura vazduha za vegetacioni period kukuruza bila je viša u drugoj godini ispitivanja (2018) i iznosila je 19,1^{0}C što je u poređenju sa 2017. godinom i višegodišnjim prosekom veća vrednost za 0,4 i 1,6^{0} C.

Tabela 2. Srednje mesečne temperature vazduha (^{o}C) za vegetacioni period kukuruza (IV–IX) u 2017. i 2018. godini (Vranje).
Table 2. Average monthly air temperatures (^{o}C) for the maize vegetation period (IV–IX) in 2017 and 2018 (Vranje).

Godina Year	Mesec/Month						Prosek Average
	IV	V	VI	VII	VIII	IX	
2017	11,5	16,2	20,7	23,3	23,4	17,2	18,7
2018	15,7	17,9	19,9	21,3	22,4	17,7	19,1
Višegod. prosek/ Long-term average (2007–2016)	10,1	15,4	18,3	20,9	20,6	17,0	17,5

Podaci o količinama padavina po mesecima vegetacionog perioda kukuruza u godinama ispitivanja, kao i višegodišnji prosek (2007–2016. godine) prikazani su u tabeli 3. Godine u kojima su obavljena ova ispitivanja su se međusobno znatno razlikovale, kako u pogledu ukupnih količina padavina u toku vegetacionog perioda kukuruza, tako i u pogledu njihovog rasporeda po mesecima.

Veća količina padavina registrovana je u 2018. godini i iznosila je 318,2 mm. Suprotno tome, u 2017. godini količina padavina za vegetacioni period kukuruza iznosila je 283,3 mm, što je u poređenju sa višegodišnjim periodom manja suma za 13,4 mm. Na osnovu iznetih podataka uočava se da su znatno povoljniji uslovi vlažnosti za gajenje kukuruza bili u 2018. godini. Nasuprot tome, u 2017. godini nedostatak padavina praćen čestom pojavom visokih maksimalnih temperatura vazduha, naročito tokom meseca jula i avgusta, bili su limitirajući faktori za realizaciju proizvodnog potencijala rodnosti ispitivanog hibrida kukuruza.

Tabela 3. Količine padavina (mm) za vegetacioni period kukuruza (IV–IX) u 2017. i 2018. godini (Vranje).
Table 3. Amounts of precipitation (mm) for the maize vegetation period (IV–IX) in 2017 and 2018 (Vranje).

Godina Year	Mesec/Month						Suma/ Sum
	IV	V	VI	VII	VIII	IX	
2017	53,2	98,4	54,4	11,5	12,0	53,8	283,3
2018	38,3	80,5	46,2	49,7	55,3	48,2	318,2
Višegod. prosek/ Long-term average (2007–2016)	52,0	58,2	51,7	47,8	35,2	51,8	296,7

Rezultati i diskusija

Dužina klipa. Rezultati naših istraživanja pokazuju da je, u proseku za ispitivane faktore, dužina klipa iznosila 17,9 cm (tabela 4). U 2017. godini izmerena je veća dužina klipa za samo 0,1 cm u odnosu na 2018. godinu. U proseku za godine i varijante gustine setve, na zemljištu tipa aluvijum utvrđena je veća dužina klipa za 0,3 cm i 0,8 cm u poređenju sa smonicom i gajnjačom. U proseku za tipove zemljišta i godine, najmanja dužina klipa (17,6 cm) izmerena je u najređoj setvi (c_1).

Na tretmanu c_3 i c_2 utvđena je veća dužina klipa za 0,1 cm i 0,9 cm. U radu Savković (2016) dužina klipa kukuruza bila je u rasponu od 19,98 cm na kontrolnom tretmanu navodnjavanja (a_1) do 20,17 cm na tretmanu navodnjavanja s najvećom normom (a3), pri čemu je hibrid vrlo značajno uticao na dužinu klipa kukuruza. U ispitivanju prinosa i komponenti prinosa komercijalnih ZP hibrida kukuruza različitih grupa zrenja, Čamdžija et al. (2012) došli su do zaključka da korelacioni koeficijenti ukazuju na značajnu međuzavisnost između prinosa i dužine klipa. Takođe, autori navode da je visoka i pozitivna korelacija između dužine klipa i broja zrna u redu očekivana. Dužina klipa je varirala od 18,17 cm kod hibrida ZP 427 do 21,11 cm za hibrid ZP 560. Slična istraživanja sproveli su Spasić et al. (2018), ukazavši da je vodni režim tokom vegetacionog perioda značajno uticao na dužinu klipa. Naime, u 2016. godini, sa najboljim rasporedom padavina, biljke kukuruza su obrazovale klipove prosečne dužine 26,9 cm. Smanjenje prosečne dužine klipa u 2015. i 2017. godini bilo je vrlo značajno prema drugoj godini. Među proučavanim genotipovima bilo je značajnih variranja u dužini klipa, kako po godinama, tako i u trogodišnjem proseku.

Tabela 4. Uticaj godine, tipa zemljišta i gustine setve na dužinu klipa (cm).
Table 4. Influence of year, soil type and sowing density on cob length (cm).

Godina Year (a)	Tip zemljišta Soil type (b)	Gustina setve/Sowing density (c)			Prosek ab Average	Indeks Index (%)
		c_1	c_2	c_3		
2017	Gajnjača Euric cambisol	18,4±0,6615	20,0±1,2754	16,5±0,4082	18,3	100,0
	Smonica Vertisol	18,0±0,6782	18,5±0,4397	17,0±0,9557	17,8	98,9
	Aluvijum Alluvium	17,0±0,2708	18,0±0,3162	18,4±0,3559	17,8	98,9
	Prosek/ Average ac	17,8	19,0	17,3	18,0	-
	Indeks/ Index (%)	100,0	106,7	97,2	-	100,0
2018	Gajnjača Euric cambisol	16,0±0,1826	17,0±0,4690	17,0±0,2944	16,7	100,0
	Smonica Vertisol	18,0±0,1826	18,4±0,3464	18,0±0,2449	18,1	108,4
	Aluvijum Alluvium	18,4±0,6164	19,0±0,7071	19,0±0,1826	18,8	116,6
	Prosek Average ac	17,5	18,1	18,0	17,9	-
	Indeks/ Index (%)	100,0	103,4	102,9	-	99,4
Prosek Average bc	Gajnjača Euric cambisol	17,2	18,5	16,8	17,5	100,0
	Smonica Vertisol	18,0	18,5	17,5	18,0	102,9
	Aluvijum Alluvium	17,7	18,5	18,7	18,3	104,4
Prosek/Average c		17,6	18,5	17,7	17,9	-
Indeks/Index (%)		100,0	105,1	100,6	-	-

Test	Nivo/Level	a	b	c	ab	ac	bc	abc
F	test	$0,4745^{nz}$	8,6884**	24,6975**	23,8351**	13,7767**	10,8578**	10,6835**
LSD	0,05	0,3389	0,4150	0,2805	0,5870	0,3967	0,4858	0,6871
	0,01	0,4643	0,5686	0,3761	0,8042	0,5319	0,6514	0,9213

Broj redova zrna na klipu. Rezultati naših istraživanja pokazuju da je, u proseku za ispitivane faktore, broj redova zrna na klipu iznosio 17,8 (tabela 5). U 2018. godini izbrojan je veći broj redova zrna na klipu za 0,3 u odnosu na 2017. godinu. U proseku za godine i gustine setve, na zemljištu tipa aluvijum utvrđen je veći broj redova zrna na klipu za 0,2 i 0,3 u poređenju sa smonicom i gajnjačom.

Tabela 5. Uticaj godine, tipa zemljišta i gustine setve na broj redova zrna na klipu.
Table 5. Influence of year, soil type and sowing density on the number of grain rows on the cob.

Godina Year (a)	Tip zemljišta Soil type (b)	Gustina setve/Sowing density (c)			Prosek Average ab	Indeks Index (%)
		c_1	c_2	c_3		
2017	Gajnjača Eutric cambisol	18,0±0,8165	18,0±0,8165	16,0±0,8165	17,3	100,0
	Smonica Vertisol	18,0±1,4142	18,0±0,8165	17,0±0,8165	17,7	102,3
	Aluvijum Alluvium	18,0±0,8165	18,0±0,8165	18,0±0,8165	18,0	104,0
	Prosek Average ac	18,0	18,0	17,0	17,7	-
	Indeks Index (%)	100,0	100,0	94,4	-	100,0
2018	Gajnjača Eutric cambisol	18,0±0,8165	18,0±0,8165	18,0±0,8165	18,0	100,0
	Smonica Vertisol	18,0±0,0000	18,0±0,8165	18,0±0,8165	18,0	100,0
	Aluvijum Alluvium	18,0±0,8165	18,0±0,8165	18,0±0,8165	18,0	100,0
	Prosek Average ac	18,0	18,0	18,0	18,0	-
	Indeks Index (%)	100,0	100,0	100,0	-	101,7
Prosek Average bc	Gajnjača Eutric cambisol	18,0	18,0	17,0	17,7	100,0
	Smonica Vertisol	18,0	18,0	17,5	17,8	100,6
	Aluvijum Alluvium	18,0	18,0	18,0	18,0	101,7
Prosek/Average c		18,0	18,0	17,5	17,8	-
Indeks/Index (%)		100,0	100,0	97,2	-	-

Test	Nivo/Level	A	b	c	ab	ac	bc	Abc
F	Test	2,5714 nz	0,8571 nz	3,0000 nz	0,8571 nz	3,0000 nz	1,0000 nz	1,0000 nz
LSD	0,05	0,4367	0,5349	0,4780	0,7564	0,6760	0,8280	1,1709
	0,01	0,5983	0,7328	0,6410	1,0364	0,9065	1,1102	1,5701

U proseku za tipove zemljišta i godine, najmanji broj redova zrna na klipu (17,7) registrovan je u usevu najveće gustine setve (c_3). U varijantama c_1 i c_2 konstatovan je isti broj redova zrna na klipu (18,0). Interakcija ab, ac, bc i abc statistički nije značajna. Prema navodima autora Čamdžija et al. (2012), korelacioni koeficijenti ukazuju na visoku i veoma visoku zavisnost između prinosa i broja redova zrna, prinosa i dužine klipa, dužine klipa i broja zrna u redu. Značajna i pozitivna korelacija između prinosa i broja redova zrna ukazuje da selekcija na veći broj zrna ima pozitivan uticaj na povećanje prinosa. S obzirom na to da su svi hibridi sejani na gustinu 67.000 biljaka po ha, ovakva gustina više pogoduje hibridima grupe zrenja FAO 300-500 nego kasnijim i silažnim hibridima.

Tabela 6. Uticaj godine, tipa zemljišta i gustine setve na broj sterilnih biljaka (%).
Table 6. Influence of year, soil type and sowing density on the number of sterile plants (%).

Godina Year (a)	Tip zemljišta Soil type (b)	Gustina setve/Sowing density (c)			Prosek Average ab	Indeksni poeni/Index points
		c_1	c_2	c_3		
2017	Gajnjača Eutric cambisol	15,00±2,1602	10,00±2,1602	6,00±0,8165	10,30	100,0
	Smonica Vertisol	2,00±0,8165	4,00±0,8165	1,50±0,5774	2,50	24,3
	Aluvijum Alluvium	4,00±0,8165	3,00±0,0000	3,70±0,4761	3,60	35,2
	Prosek/ Average ac	7,00	5,70	3,70	5,50	-
	Indeksni poeni/ Index points	100,0	81,4	52,9	-	100,0
2018	Gajnjača Eutric cambisol	1,00±0,8165	0,50±0,4082	0,10±0,0816	0,50	100,0
	Smonica Vertisol	0,00±0,0000	0,00±0,0000	0,00±0,0000	0,00	-
	Aluvijum Alluvium	0,00±0,0000	0,00±0,0000	0,00±0,0000	0,00	-
	Prosek/ Average ac	0,30	0,20	0,03	0,20	-
	Indeksni poeni/ Index points	100,0	66,7	10,0	-	3,6
Prosek bc	Gajnjača Eutric cambisol	8,00	5,30	3,10	5,50	100,0
	Smonica Vertisol	1,00	2,00	0,80	1,30	23,6
	Aluvijum Alluvium	2,00	1,50	1,90	1,80	32,7
Prosek/Average c		3,70	2,90	1,90	2,90	-
Indeksni poeni/ Index points		100,0	78,4	51,4	-	-

Test	Nivo/Level	a	b	C	ab	ac	bc	abc
F	Test	353,5646**	87,3753 **	47,5551**	65,5038 **	33,1222**	42,0027**	29,1185**
LSD	0,05	0,5909	0,7237	0,3724	1,0235	0,5267	0,6450	0,9122
	0,01	0,8096	0,9916	0,4994	1,4023	0,7062	0,8649	1,2232

Ranijim hibridima (FAO 300-500) je omogućeno da iskažu pun potencijal ispitivanih svojstava poput broja redova zrna, broja zrna u redu i dužine klipa zbog manje kompetitivnosti biljaka u usevu, jer se radi o hibridima nižeg habitusa (Mukhtar et al., 2012).

Broj sterilnih biljaka. Rezultati naših istraživanja pokazuju da je, u proseku za ispitivane faktore, procenat sterilnih biljaka iznosio 2,90% (tabela 6). U 2017. godini utvrđen je veći broj sterilnih biljaka za 5,30% u odnosu na 2018. godinu.

U proseku za godine i varijante gustine setve, na zemljištu tipa gajnjača zabeležen je veći procenat sterilnih biljaka za 3,70% i 4,20% u poređenju sa aluvijumom i smonicom. U proseku za tipove zemljišta i godine, najmanji procenat sterilnih biljaka (1,90%) konstatovan je pri najgušćoj setvi (75.187 biljaka po ha), veći (2,90%) u srednjoj gustini (68.027 biljaka po ha) i najveći (3,70%) u najređoj setvi (64.935 biljaka po ha). Interakcije ab, ac, bc i abc statistički su vrlo signifikantne. Andrade et al. (1996) su utvrdili povećanje broja zrna po jedinici površine sterilnih u odnosu na fertilne hibride u optimalnoj setvenoj gustini. Stamp et al. (2000) su kod dva hibrida i jedne populacije ispitivali uticaj CMS, a ispitivani su genotipovi sa fertilnom i sterilnom citoplazmom u T tipu. Sterilna populacija imala je 23,2% viši prinos zrna u odnosu na fertilnu verziju. Kod oba hibrida došlo je do povećanja prinosa zrna u odnosu na fertilnu verziju, koje je kod boljeg, u većoj setvenoj gustini, iznosilo i do 19%, a povećanje je došlo preko povećanja mase hiljadu zrna i broja zrna po klipu. Weingartner et al. (2002) su ukazali da sterilnost utiče na povećanje prinosa kod hibrida kukuruza, ali ne značajno.

Prinos zrna. Rezultati naših istraživanja pokazuju da je, u proseku za ispitivane faktore, prinos zrna iznosio 5.195 kg/ha (tabela 7). U 2018. godini dobijen je veći prinos zrna za 1.189 kg/ha ili 25,8% u odnosu na 2017. godinu. U proseku za godine i gustine setve, na zemljištu tipa smonica i aluvijum postignut je veći prinos zrna za 1.200 kg/ha i 3.083 kg/ha u poređenju sa gajnjačom. U proseku za tipove zemljišta i godine, najmanji prinos zrna (4.533 kg/ha) konstatovan je u najređoj setvi (64.935 biljaka po ha). Sa povećanjem gustine setve do 68.027 biljaka po ha, prinos zrna se povećavao (za 1.000 kg/ha ili 22,0%), a zatim neznatno smanjivao. Interakcije ab, ac, bc i abc statistički su vrlo signifikantne. Prinos zrna kukuruza zavisi od hibrida, agroekoloških uslova i nivoa primenjene tehnologije gajenja. Da visina prinosa zrna kukuruza u velikoj meri zavisi od vremenskih uslova tokom vegetacionog perioda, a naročito količine i rasporeda padavina, potvrđuju rezultati mnogih istraživača. Kako navodi Jevtić (1986), uticaj hibrida iznosi 46–51%, agroekoloških uslova 9–23%, a agrotehnike 31–40%. U radu Živanović et al. (2019), u trogodišnjem proseku, na prinos zrna kukuruza najjači uticaj je ispoljio tip zemljišta, zatim đubrenje azotom i najslabiji hibrid. Na zemljištu tipa černozem, prosečan prinos zrna bio je veći za 1,97 t/ha odnosno za 22,5% u poređenju sa gajnjačom. Pojačana ishrana azotom uslovila je povećanje prinosa zrna za 0,92 do 1,25 t/ha ili za 9,9 do 13,5%. Efekat đubrenja azotom na prinos zrna bio je izraženiji na gajnjači nego na černozemu. Najmanji prosečan prinos zrna kukuruza (9,49 t/ha) ustanovljen je kod hibrida ZP 434, veći (9,75 t/ha) u hibrida ZP 578 i najveći (10,03 t/ha) u hibrida ZP 677. Spasić et al. (2018) došli su do rezultata da je prinos zrna u trogodišnjem proseku za ceo ogled iznosio 7.470 kg/ha, uz statistički vrlo značajna variranja po godinama. Nepovoljni vremenski uslovi u prvoj (2015. godini) i trećoj godini (2017. godini) značajno su umanjili prinos zrna, posebno dugi sušni periodi praćeni visokim temperaturama vazduha u 2017. godini.

Tabela 7. Uticaj godine, tipa zemljišta i gustine setve na prinos zrna (kg/ha).
Table 7. Influence of year, soil type and sowing density on grain yield (kg/ha).

Godina Year (a)	Tip zemljišta Soil type (b)	Gustina setve/Sowing density (c)			Prosek Average ab	Indeks Index (%)
		c_1	c_2	c_3		
2017	Gajnjača Eutric cambisol	3,200±0,3367	4,000±0,0816	3,000±0,1826	3,400	100,0
	Smonica Vertisol	3,800±0,2160	5,000±0,0816	4,500±0,0816	4,433	130,4
	Aluvijum Alluvium	5,400±0,1826	6,000±0,1291	6,500±0,0816	5,967	175,5
	Prosek Average ac	4,133	5,000	4,667	4,600	-
	Indeks/ Index (%)	100,0	121,0	112,9	-	100,0
2018	Gajnjača Eutric cambisol	3,900±0,0816	4,500±0,0816	4,000±0,1826	4,133	100,0
	Smonica Vertisol	4,400±0,1826	5,600±0,2160	6,500±0,2160	5,500	133,1
	Aluvijum Alluvium	6,600±0,1633	8,100±0,0816	8,500±0,2160	7,733	187,1
	Prosek Average ac	4,967	6.067	6.333	5,789	-
	Indeks/ Index (%)	100,0	122,1	127,5	-	125,8
Prosek Average bc	Gajnjača Eutric cambisol	3,550	4,250	3,500	3,767	100,0
	Smonica Vertisol	4,100	5,300	5,500	4,967	131,9
	Aluvijum Alluvium	6,000	7,050	7,500	6,850	181,8
Prosek/Average c		4,533	5,533	5,500	5,195	-
Indeks/Index (%)		100,0	122,0	121,3	-	-

Test	Nivo Level	a	b	c	ab	Ac	bc	abc
F	Test	599,5903**	1387,0441**	334,2049**	38,3392**	49,6475**	71,3607**	16,9672**
LSD	0,05	0,6287	0,7699	0,3625	1,0889	0,5126	0,6278	0,8879
	0,01	0,8613	1,0549	0,4861	1,4918	0,6874	0,8419	1,1906

Sadržaj vode u zrnu. Rezultati naših istraživanja pokazuju da je, u proseku za ispitivane faktore, sadržaj vode u zrnu iznosio 13,6% (tabela 8). U 2018. godini izmeren je veći sadržaj vode u zrnu za 8,5 indeksnih poena u odnosu na 2017. godinu. U proseku za godine i gustine setve, na zemljištu tipa smonica i aluvijum utvrđen je veći sadržaj vode u zrnu za 20,3 i 25,4 indeksna poena u odnosu na gajnjaču.

Tabela 8. Uticaj godine, tipa zemljišta i gustine setve na sadržaj vode u zrnu (%).
Table 8. Influence of year, soil type and sowing density on grain water content (%).

Godina Year (a)	Tip zemljišta Soil type (b)	Gustina setve/Sowing density (c)			Prosek Average ab	Indeksni poeni/Index points
		c_1	c_2	c_3		
2017	Gajnjača Eutric cambisol	11,0±0,4082	12,8±4,3008	11,4±0,4082	11,7	100,0
	Smonica Vertisol	12,5±0,1826	13,0±0,1826	14,1±0,1826	13,2	112,8
	Aluvijum Alluvium	14,4±0,1826	13,9±0,2160	14,0±0,1826	14,1	120,5
	Prosek Average ac	12,6	13,2	13,2	13,0	-
	Indeksni poeni/ Index points	100,0	104,8	104,8	-	100,0
2018	Gajnjača Eutric cambisol	12,1±0,2160	12,0±0,2944	11,4±0,2309	11,8	100,0
	Smonica Vertisol	15,0±0,1826	15,4±0,2944	15,2±0,4082	15,2	128,8
	Aluvijum Alluvium	15,0±0,2449	14,7±0,3559	16,5±0,4163	15,4	130,5
	Prosek Average ac	14,0	14,0	14,4	14,1	-
	Indeksni poeni/ Index points	100,0	100,0	102,9	-	108,5
Prosek Average bc	Gajnjača Eutric cambisol	11,6	12,4	11,4	11,8	100,0
	Smonica Vertisol	13,8	14,2	14,7	14,2	120,3
	Aluvijum Alluvium	14,7	14,3	15,3	14,8	125,4
Prosek/Average c		13,4	13,6	13,8	13,6	-
Indeksni poeni/Index points		100,0	101,5	103,0	-	-

Test	Nivo/Level	a	b	c	ab	ac	bc	Abc
F	Test	23,1593**	51,5257**	2,0952 nz	1,2642nz	0,2449 nz	0,9794 nz	2,4708 nz
LSD	0,05	0,6088	0,7456	0,5556	1,0544	0,7858	0,9624	1,3610
	0,01	0,8341	1,0215	0,7451	1,4446	1,0537	1,2905	1,8250

U proseku za tipove zemljišta i godine, najmanji sadržaj vode u zrnu (13,4%) zabeležen je u najređoj setvi (c_1), veći (13,6%) u varijanti c_2 i najveći (13,8%) u varijanti c_3, odnosno najgušćoj setvi (75.187 biljaka po ha). Interakcije ab, ac, bc i abc nisu statistički značajne. Sadržaj vode u zrnu je pokazatelj od izuzetne važnosti sa aspekta ekonomičnosti proizvodnje kukuruza, naročito u pogledu troškova sušenja i skladištenja kukuruza u zrnu. Takođe, različiti vodni režimi (različite varijante navodnjavanja) utiču na promenu hemijskog sastava zrna kukuruza, kao i na promenu hranljive vrednosti zrna.

U zrnu kukuruza veća suma vode tokom vegetacionog perioda utiče na povećanje sadržaja proteina i ulja, a na smanjenje procenta skroba, celuloze i mineralnih soli (Jaramaz, 2015). U istraživanju koje je sproveo Živanović (2012) u periodu od 2005. do 2007. godine, sadržaj vode u zrnu kukuruza u trogodišnjem proseku iznosio je 25,3%, pri čemu je od ispitivanih faktora (tip zemljišta – černozem i gajnjača, količina azota i hibrid), statistički vrlo značajno uticao samo hibrid. Prema navodu Jaramaz (2015), variranja u sadržaju vode u zrnu po godinama istraživanja (2011–2013) ukazuju da je ova kvalitativna osobina zrna zavisila od količine i rasporeda padavina, ali i od toplotnih uslova. Kukuruz je u najvlažnijoj 2011. godini imao najveći sadržaj vode u zrnu – 30,43%. U trogodišnjem proseku najmanji sadržaj vode bio je u varijanti najmanje gustine setve – 25,62%, a povećanjem gustine rastao je i sadržaj vode do 26,03% u najvećoj gustini.

Zaključak

Godine u kojima su obavljena istraživanja uticaja tipa zemljišta i hibrida na produktivnost kukuruza, bitno su se razlikovale u pogledu meteoroloških uslova, kako u količini i rasporedu padavina, tako i u toplotnim uslovima. Na zemljištu tipa aluvijum izmerena je najveća dužina klipa (18,3 cm), broj redova zrna na klipu (18,0), kao i najveći broj biljaka po ha u berbi (67.167). Na zemljištu tipa gajnjača utvrđen je najveći broj sterilnih biljaka (5,5%). Sa povećanjem gustine setve, dužina klipa se povećala do gustine c_2, dok je najveći sadržaj vode u zrnu registrovan u najgušćoj setvi (c_3). Broj redova zrna nije značajno varirao u zavisnosti od gustine setve. Prinos zrna kukuruza varirao je u značajnoj meri u zavisnosti od vremenskih uslova godine. U poređenju sa 2017. godinom, koja je okarakterisana kao sušna, u 2018. postignut je veći prinos zrna za 25,8%. U dvogodišnjem proseku, na prinos zrna jači uticaj je ispoljio tip zemljišta u odnosu na gustinu setve. Naša istraživanja su pokazala da je efektivna plodnost, odnosno produktivnost zemljišta tipa smonica i aluvijum za gajenje kukuruza bila veća za 31,9% i 81,8% u poređenju sa gajnjačom. Ustanovljena je međuzavisnost između tipa zemljišta i gustine setve. Na gajnjači, najveći prinos zrna (4.250 kg/ha) dobijen je pri gustini od 68.027 biljaka po ha (70 x 22 cm). Na smonici i aluvijumu najveći prinos (5.500 kg/ha i 7.500 kg/ha) je postignut u kombinaciji najgušće setve (75.187 biljaka po ha, odnosno 70 x 19 cm).

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THE EFFECT OF WEATHER CONDITIONS, SOIL TYPE AND SOWING DENSITY ON THE PRODUCTIVITY OF MAIZE

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A b s t r a c t

High maize yields can only be achieved on fertile, loose and well-permeable soils. Previous research indicates that novel maize hybrids respond favorably to higher crop density. The aim of this study was to investigate the influence of meteorological conditions, soil type and seeding density on cob length, number of grain rows on the cob, number of sterile plants, grain yield and grain water content of the maize hybrid AS 6E02 (FAO 620) during the growing season. The tests were carried out during 2017 and 2018 through field micro-experiments in the agroecological conditions of the Vranje municipality using the split-plot design with four replications on eutric cambisol, vertisol and alluvium soils. The area of the plot for grain yield was 8.4 m^2. The agronomic practices used in the experiment were standard, as for regular maize production. The years in which the surveys were conducted differed in terms of meteorological conditions, the amount and distribution of precipitation. The smallest average cob length (17.6 cm) for all investigated soils and years was obtained with the narrow-row sowing. The number of grain rows did not vary significantly depending on the sowing density. On a two-year average, the grain yield was significantly higher, influenced by the type of soil in relation to the sowing density. On average for soil types and years, the lowest percentage of sterile plants (1.90%) was found at the sowing density of 75.187 plants per ha. In comparison to 2017, the water content was higher by 8.5 index points in 2018.

Key words: maize, soil, sowing, productivity, seed yield.

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CROSS- AND SELF-POLLINATION TO EVALUATE THE YIELD CHARACTERISTICS IN F3 MELON (*CUCUMIS MELO* L.) INBRED LINES

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Abstract: This study aims to determine the percentage of pollination of a combination of cross-pollination and self-pollination in several melon inbred lines and to determine the yield character of the combination of cross-pollination and self-pollination in F3 melon inbred lines. The study was conducted in 2021 and 2022 by using nine melon inbred lines as planting material, consisting of 4 female parents (ACL211390, ACL221402, ACL221326, and ACL231312) and 5 male parents (ACD211303, ACD211254, ACD221362, ACD231380, and ACL21402). In general, the percentage of successful pollination showed various values, and the value of 100% was not obtained from all sample plants. This was because the pollination of 3 hermaphrodite flowers (female parents) on each sample plant was carried out at different times. The results of the observations of yield characteristics (fruit weight, fruit diameter, fruit length, flesh thickness, and fruit total soluble solids) showed different values between the pollination combinations in the same female parent inbred. The differences in pollen sources were responsible for the differences in yield characteristics between the pollinated combinations with the same female parent. The Student's t-test between the inbreds ACL211390, ACL221402, ACL221326, and ACL231312 (female parent) showed that there was no significant difference in the mean percentage of pollination success and that there were significant to very significant differences in several yield characters. The difference in yield characters was due to differences in the composition of genetic material between the inbreds ACL211390, ACL221402, ACL221326, and ACL231312.

Key words: cross-pollination, inbred, melon, self-pollination, pollination.

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Introduction

The melon (*Cucumis melo* L.) is one of the horticultural plants from the Cucurbitaceae family and is favored for its fruit because it has a sweet, fresh taste, and is rich in nutrients. In addition, the melon is a healthy fruit that contains lots of vitamins, proteins, and carbohydrates. The origin of the melon plant is not known for sure. However, the wild species of Cucumis suggest that melon plants came from the African continent. However, recent research suggests that melons originate from Asia (Shashikumar and Pitchaimuthu, 2016). The melon is a plant with high economic value and therefore has the potential to be developed. However, melon production has decreased from year to year. The demand for good quality melons will increase as people's lifestyles change and they begin to pay attention to what they eat. The increased production value of melons affects the availability of seeds as planting material. The demand for the continuous availability of seeds causes an increase in seed production activities. This is followed by an increase in superior melon seeds. However, the availability of domestic melon seed production and quality seed varieties is not sufficient to meet the needs.

The superior seeds need to be developed, aiming to obtain unique melons that meet market needs and can adapt to various environmental conditions. There are several methods to produce superior melon seeds in plant breeding, one of which is pollination. Pollination is the process of transferring pollen from the anther to the receptive stigma (Ren et al., 2018). The failure of artificial pollination and melon fruit formation is still quite high. This is because the formation of melon fruits and seeds depends on the stigma receptive period of the pollen viability. The amount of pollen used in the artificial pollination process can also greatly affect the success of pollination. The availability of pollen in one male flower with good viability is expected to pollinate more than one female flower under optimum conditions (Pattemore, 2017).

Another factor that affects pollination success in melons is the genetic compatibility of the pollen used during self-pollination and cross-pollination (Duarte et al., 2017). In addition, environmental factors such as temperature and humidity also greatly affect pollination success. Studies have shown that high temperatures can reduce pollen viability, while optimal humidity levels can enhance pollen germination and tube growth (Koch et al., 2017). Thus, the selection of compatible hybrids with superior characters is very important in increasing pollination yield. Ideal environmental controls such as temperature and humidity settings as well as the timing of pollination in a controlled environment are important factors to consider. Research shows that the optimal time for pollination is in the morning when the flowers are most receptive to pollen (Henrique et al., 2015). In a controlled environment, breeders can also synchronize the flowering periods of different melon varieties to facilitate cross-pollination. This synchronization is critical to ensure that compatible pollen is available when flowers are receptive, thus maximizing the chances of successful fertilization (Suhri et al., 2022).

One of the initial considerations in selecting hybrid parents can be through cross-pollination between inbreds currently in the purification stage, such as F3, F4, etc. This is to predict the success of cross-pollination and to predict inbred candidates that have the potential to be hybrid parents by observing differences in the character of the fruit from cross-pollination. The study results are expected to provide information on the success rate of cross-pollination and yield characteristics in each cross-pollination combination so that it can be considered in the selection of inbred candidates for the development of superior hybrid melon seeds (Handayani et al., 2022).

Material and Methods

The research was conducted at the Brawijaya University Greenhouse located in Donowarih Village, Karangploso District, Malang Regency, East Java Province. The Donowarih Village is located at an altitude of 720 masl with an average annual rainfall of 250 mm/month and an average temperature of 27°C. The research was carried out in 2021 and 2022 when the rain intensity was low.

The genetic material used comprised nine inbred lines of melon (F3), consisting of 4 as female parents and 5 as male parents. The following 9 melon inbred parents are ACD211303 (A), ACD211254 (B), ACD221362 (C), ACD231380 (D), ACL211390 (F), ACL211402 (G), ACL221402 (H), ACL221451 (I) and ACL231312 (J). The research was carried out by self-pollinating 4 melon inbreds and cross-pollinating them with 5 different inbreds (male parents). The number of plants used in the study was 48 plants with 2 plants in each combination. Each female parent plant was pollinated with 3 hermaphrodite flowers that had previously been emasculated. The pollination was not carried out simultaneously (day), but when the hermaphrodite flowers were ready for pollination. The total number of hermaphrodite flowers pollinated in this study was 144. The seedlings were planted 14 days before transplanting. Fertilization was carried out once a week in the form of a solution with different doses of fertilizer given. When fertilizing the plants at the age of 10 DAP, the fertilizer KNO3 Merah was administered at a dose of 7.95 g per 8 liters of water. Plants aged 20–35 DAP received fertilizer in the form of NPK compound fertilizer at a dose of 11.3 g per 8 liters of water. Plants aged 40–50 DAP received Multi KP fertilizer at a dose of 9.09 g per 8 liters of water. Melon plant-insect pest control was carried out using insecticide Curacorn 500 EC and Decis 25 EC. Melon plant disease control was conducted using fungicides Antracol 70 WP, Dithane M-45 80 WP, and Agri-mycin 17.

The observational data were presented in tables and then analyzed. Data analysis was performed using an unpaired Student's t-test at the 5% level using the SPSS software. The unpaired Student t-test analysis was used to compare the mean percentage of pollination success and the yield characteristics between self-pollination and cross-pollination. The following are the test criteria and the formula for analyzing variance of the unpaired t-test:

-Taccount < Ttable or Taccount > Ttable = then there is a difference between the groups,

-Ttable Tcount Ttable = there is no difference between the groups,

if the variance is homogeneous, then: if the variance is not homogeneous, then:

$$T_{count} = \frac{x1 - x2}{\sqrt{s2p\,(\frac{1}{n1} + \frac{1}{n2})}} \qquad T_{count} = \frac{x1 - x2}{\sqrt{\frac{S12}{n1} + \frac{S22}{n2}}}$$

information: 1 = the average of the 1st sample, 2 = the average of the 2nd sample, sp 2 = the variance of the sample, n1 = the number of the 1st sample, n2 = the number of the 2nd sample, s2 1 = the variance of the sample to -1, s2 2 = the variance of the 2nd sample (Source: Ireland, 2010).

Before the t-test, normality and homogeneity tests were conducted to determine whether the data met the requirements for the t-test. The homogeneity of variance test was carried out using the Levene's test. The following are the criteria and formulas for the homogeneity of the variance test from the Levene's test.

F_{count} F_{table} atau Sig. ≤ α = the variance of all groups is not homogeneous,

$F_{count} < F_{table}$ atau Sig. > α = the variance of all homogeneous groups,

$$F_{count} = \frac{(N\text{-}K)\sum_{i=1}^{k} n_i\,(\bar{d}_i - \bar{d}_{ii})^2}{(k\text{-}1)\sum_{i=1}^{k}\,(\bar{d}_i - \bar{d}_{ii})^2}$$

information: N = the total number of samples, ni = the number of samples to-I, K = the number of sample groups, di = the value of the sample difference to the group mean, dii = the value of the difference between the groups to the mean differentiated between the groups (Aminoto and Agustina, 2020).

The normality test was carried out using the Shapiro-Wilk test. According to Ahsanullah et al. (2014), the hypotheses and the Shapiro-Wilk test formula are as follows:

a. Shapiro-Wilk test hypothesis for normality,

H0: the data is normally distributed,

H1: the data is not normally distributed,

(H0 is accepted if W > W table or Sig. > α).

b. Statistical formula of the Shapiro-Wilk test

$$W = \frac{\sum_{i=1}^{k} a_i \, (y_{n-i+1} - y_i)^2}{\sum_{i=1}^{n} \, (x_i - \bar{x})^2}$$

information: W = Shapiro-Wilk test statistic, k = n/2, i = coefficient, yi = observational data in the first sample, y n-i+1 = observational data in the (n- i+1), n = the number of samples, xi = the value of the sample, x = the sample mean.

Results and Discussion

Crosses between several melon inbreds

The percentage of successful pollination of several inbreds tested on each sample plant and the average per pollination combination are presented in Table 1. The results of 4 inbreds (ACL211390, ACL221402, ACL221326, and ACL231312) with one pollination treatment on 3 hermaphrodite flowers per plant show a high mean of pollination success. The results of the calculations for the inbred ACL211390 and ACL221326 showed that the self-pollination treatment had a higher average pollination success (67%) than the cross-pollination treatment. Furthermore, the ACL221402 inbred showed that the cross-pollination treatment with the ACD211303 inbred had a higher mean of pollination success (67%) than the other treatments, followed by the ACL221326 inbred crossed with ACD211303. In addition, the ACL231312 inbred also showed that the cross-pollination treatment with the ACL211402 inbred had a higher pollination success rate (67%) than the other treatments. The percentage of successful pollination was obtained by comparing the successful pollination with the total pollination carried out on each plant sample. Table 1 shows the percentage of successful pollination in each plant sample and the average per treatment. Based on these observations, a t-test analysis was performed to determine if there was a difference in the percentage of successful pollination between the inbreds of ACL211390, ACL221402, ACL221326, and ACL231312 (Table 2). The results of the t-test analysis between the inbreds ACL211390, ACL221402, ACL221326, and ACL231312 show that the percentage of pollination success was not significantly different. The insignificant difference is because both pollination methods can produce good melon fruit, but the difference lies in the resulting impact, namely self-pollination can increase genetic depression and cross-pollination can increase genetic diversity. In addition, the results of cross-pollination are of higher quality than the results of self-pollination (Taber and Olmstead, 2016; Kämper et al., 2021). The success of pollination in this case is not therefore influenced by self-pollination and cross-pollination techniques, but by other factors such as the maturity of the pollen or pistil at the time of pollination.

Table 1. Cross percentage.

Treatment	Cross percentage (%)		Average (%)
	Sample 1	Sample 2	
Self-pollination			
ACL211390 X ACL211390	67	67	67
ACL221402 X ACL221402	33	33	33
ACL221326 X ACL221326	67	67	67
ACL231312 X ACL231312	33	33	33
Cross-pollination			
ACL211390 X ACD211303	67	33	50
ACL211390 X ACD211254	33	33	33
ACL211390 X ACD221362	33	67	50
ACL211390 X ACD231380	33	33	33
ACL211390 X ACL211402	33	33	33
ACL221402 X ACD211303	67	67	67
ACL221402 X ACD211254	33	67	50
ACL221402 X ACD221362	33	33	33
ACL221402 X ACD231380	67	33	50
ACL221402 X ACL211402	33	33	33
ACL221326 X ACD211303	67	33	50
ACL221326 X ACD211254	67	67	67
ACL221326 X ACD221362	67	33	50
ACL221326 X ACD231380	33	67	50
ACL221326 X ACL211402	33	33	33
ACL231312 X ACD211303	33	67	50
ACL231312 X ACD211254	33	33	33
ACL231312 X ACD221362	33	67	50
ACL231312 X ACD231380	33	33	33
ACL231312 X ACL211402	67	67	67
Average (%)			46

Table 2. Results of the t-test percentage of inbred pollination.

Inbred	T-count
ACL211390 and ACL 221402	-0.94 ns
ACL211390 and ACL221326	0.24 ns
ACL211390 and ACL 231321	0.00 ns
ACL221402 and ACL221326	-0.42 ns
ACL221402 and ACL231312	-0.94 ns
ACL221326 and ACL231312	0.42 ns

Information: (*) *t*-value significant at 0.05, (**) *t*-value significant at 0.01 and (ns) *t*-value not significant.

Pollination is considered successful if the ovules of the pollinated hermaphrodite flowers (female elders) remain green and develop into fruit. Meanwhile, the pollination is considered to have failed when the ovules wilt and turn yellow and then fall off. Overall, the 4 inbreds show that of the 3 hermaphrodite flowers (female parents) per pollinated plant, the average percentage of pollination success was different or varied and there was no result where the percentage of pollination success was equal to 100% for all sample plants. Pattemore (2017) stated that the success of pollination can be influenced by the receptivity of the stigma when receiving pollen. Furthermore, Hasanuddin (2013) has stated that maximum stigma receptivity occurs when the flowers bloom and the day after blooming, while maximum pollen viability is reached one day after blooming. At the time of the study, the melon plant flowers bloomed in the morning. Synchronization between the time of flowering of the female and male flowers is also one of the factors that determine the success of fertilization in crosses. This is related to the readiness of the pistil for pollen tube growth. According to Vidal et al. (2010), the success of hybridization also depends on the efficiency of the pollinator during the receptive female flower period and the viability of the pollen used. The implication of successful pollination is key in the early stages of variety assembly for both self-pollinated and cross-pollinated crops. In the case of this melon study, the pollination method did not differ significantly between self-pollination and cross-pollination. However, the method had an impact on fruit yield and quality, as cross-pollinated fruits were always heavier than self-pollinated fruits of the same cultivar, which is highly correlated with the number of seeds per fruit (Taber and Olmstead, 2016). Similar studies have also shown that fruits produced by cross-pollination tend to be larger and sweeter than those produced through self-pollination (Suhri et al., 2022). The findings of this study can therefore contribute to the development of melons. Paying attention to the success factors of pollination is the key to obtaining optimal results from the results of self-pollination and cross-pollination.

Yield characteristics of several melon inbred crosses

The observed yield characteristics included fruit weight, fruit length, fruit diameter, fruit flesh thickness, and fruit total soluble solids. The pollinated characters of the inbreds of ACL211390, ACL221402, ACL221326, and ACL231312 are shown in Table 3. The pollination results for the inbred ACL211390 show that the highest mean fruit weight (964.50 g), fruit diameter (12.53 cm), fruit length (10.92 cm), and fruit flesh thickness (2.85 cm) were found in the ACL211390 X ACL21402 cross-pollination treatment. The highest average fruit sweetness (13°Brix) was found in the ACL211390 X ACD221362 treatment. Two treatments with cross-pollination (ACL211390 X ACD211254 and

ACL211390 X ACL21402) had higher fruit weight than those with self-pollination (629.0 g). Cross-pollination has been shown to improve fruit quality, with fruits that are often larger, sweeter, and more uniform in size compared to those produced through self-pollination (Pérez-Marcos et al., 2023). The quantity of yield associated with cross-pollination is generally higher than with self-pollination. Studies show that cross-pollinated melons can achieve significantly greater yields due to better fruit formation and quality (Atmowidi et al., 2022). These yield differences can be the basis for the development of higher-yielding and sweeter melons through cross-pollination methods. However, crossing techniques such as pollen distribution and plant microclimate also need to be considered for optimal cross-pollination results. Similar studies have shown that even pollen distribution across the pistil is important for fruit development and increased yield and fruit quality (Wietzke et al., 2018). According to Tatari et al. (2018), fruit formation is also influenced by temperature, humidity, and insect activity.

The results of pollination on the inbred ACL221402 show that the highest average fruit weight (749.50 g), fruit diameter (11.02 cm), fruit length (10.88 cm), and fruit flesh thickness (2.48 cm) were found in the self-pollinated treatment. The highest average fruit total soluble solids (14.10°Brix) were found in treatments ACL221402 X ACD211254 and ACL221402 X ACD231380. Overall, the inbred of ACL221402 in the cross-pollination treatment had a lower fruit weight than in the self-pollination treatment (749.50 g). Three cross-pollinated treatments (ACL221402 X ACD211303, ACL221402 X ACD221362 and ACL221402 X ACD231380) had a higher average fruit sweetness than the self-pollinated treatment (12.70°Brix). The sweetness or increased sugar content in melons and the fruit weight are the most important indicators of melon quantity and quality. Self-pollination results that show lower weights, while some studies such as Pérez-Marcos et al. (2023) and Suhri et al. (2022) showed higher weights, can be caused by pollen distribution, which is related to the technical conditions of field cross-pollination and nutrient availability. Similar studies have shown that the increase in size, weight, sweetness, and number of seeds is due to the even distribution of pollen on the pistil (Huang et al., 2017). In addition, higher pollen counts can result in better seed set and heavier fruit, emphasizing the importance of selecting compatible pollen sources (Kendall et al., 2020). Thus, the selection of parents with superior and competent traits is the main basis for increasing the yield of cross-pollination in melons. Similar studies have also shown that cross-pollinated seeds often produce more auxin, a growth-promoting plant hormone, compared to self-pollinated seeds (Dung et al., 2022). This hormonal advantage can result in faster fruit development and larger fruits.

The ACL221326 inbred showed the highest mean fruit weight (804.0 g), the largest fruit diameter (12.00 cm), and the greatest pulp thickness (2.81 cm) found in the self-pollinated treatment. Meanwhile, the highest mean fruit length (10.85

cm) was found in the cross-pollination ACL221402 X ACD211254 treatment and fruit total soluble solids (13.00 °Brix) were found in the ACL211390 X ACD221362 treatment. Overall, the inbred of ACL221326 in the cross-pollination treatment had lower fruit weight, fruit diameter, and flesh thickness than in the self-pollinated treatment. According to Shafique et al. (2011), different pollen sources have different pollen viability, germination percentage, and genetic composition, which can affect the process of fruit formation.

Table 3. The mean of the inbred characters of ACL211390, ACL221402, ACL221326, and ACL231312 self-pollinated and cross-pollinated.

Treatment	FW (g)	FD (cm)	FL (cm)	FFT (cm)	FTSS (°Brix)
Self-pollination					
ACL211390 X ACL211390	629.0	10.97	9.96	2.38	9.30
ACL221402 X ACL221402	749.5	11.02	10.88	2.48	12.70
ACL221326 X ACL221326	804.0	12.00	10.15	2.81	10.90
ACL231312 X ACL231312	507.5	10.50	8.75	2.17	10.73
Cross-pollination					
ACL211390 X ACD211303	571.5	10.89	8.70	2.10	11.00
ACL211390 X ACD211254	866.0	12.15	10.43	2.83	10.20
ACL211390 X ACD221362	640.5	10.73	10.17	2.38	13.00
ACL211390 X ACD231380	353.5	8.97	8.41	1.70	9.40
ACL211390 X ACL211402	964.5	12.53	10.92	2.85	10.10
ACL221402 X ACD211303	393.0	9.08	8.53	1.53	13.20
ACL221402 X ACD211254	616.0	10.25	10.85	1.85	11.90
ACL221402 X ACD221362	418.5	9.24	9.48	1.82	13.60
ACL221402 X ACD231380	579.5	10.60	9.18	2.07	14.10
ACL221402 X ACL211402	528.5	9.90	9.27	2.25	12.10
ACL221326 X ACD211303	823.5	11.87	9.95	2.46	10.1
ACL221326 X ACD211254	697.5	10.50	9.18	2.35	9.8
ACL221326 X ACD221362	665.5	11.41	8.8	2.53	10.66
ACL221326 X ACD231380	834.5	12.39	9.85	2.83	11.20
ACL221326 X ACL211402	829.0	11.60	10.15	2.55	11.20
ACL231312 X ACD211303	687.0	11.35	10.24	2.34	13.10
ACL231312 X ACD211254	658.5	10.93	10.37	2.27	12.80
ACL231312 X ACD221362	721.5	11.53	9.90	2.25	8.70
ACL231312 X ACD231380	422.0	9.22	9.72	1.93	10.40
ACL231312 X ACL211402	692.5	11.36	10.64	2.18	12.55

Information: (FW) fruit weight, (FD) fruit diameter, (FL) fruit length, (FFT) fruit flesh thickness, (FTSS) fruit total soluble solids.

Overall, except for ACL231312 X ACL21402, the inbred of ACL231312 in the cross-pollination treatment had higher fruit weight than in the self-pollination treatment (507.5 g) and there were three cross-pollination treatments (ACL231312

X ACD211303, ACL231312 X ACD211254, and ACL231312 X ACL21402) which had higher fruit total soluble solids than self-pollination treatment (10.73°Brix). The inbred of ACL231312 showed cross-pollination results with the inbred of ACD221362 having the higher average fruit weight (721.50 g) and fruit diameter (11.53 cm) than the other treatments. Then, the highest average fruit length (10.64 cm) was found in the ACL231312 X ACL211402 treatment. The highest mean thickness of fruit flesh (2.34 cm) and the highest fruit total soluble solids (13.1°Brix) were found in the cross-pollination treatment ACL231312 X ACD211303. The yield potential of melons is not only influenced by the pollination technique, but also by the pollen source. Thus, the compatibility of the pollen source with the target cultivar must be assessed. Pollen from closely related cultivars is more likely to result in successful fertilization and higher fruit quality. Similar studies have shown that higher pollen counts can result in better seed set and heavier fruit, emphasizing the importance of selecting compatible pollen sources (Kendall et al.*,* 2020). Similar studies have shown that different pollen sources can lead to variations in fruit weight and diameter. Certain pollen donors have been associated with increased fruit weight, as well as larger fruit dimensions (Deng et al.*,* 2022). These relationships highlight the importance of selecting the right pollen donor to optimize these traits in melons. Yield characters are highly related and positively correlated, although fruit weight and sweetness are the main indicators. Similar research showed that traits such as fruit length, diameter, and flesh thickness were significantly correlated with fruit weight, indicating that these morphological traits are important for assessing genetic variability and yield potential in breeding programs (Ivanova and Velkov, 2021).

Table 4 shows that the fruit weight of the inbred ACL211390 was not significantly different from the inbreds of ACL221402 and ACL231312, ACL221402 and ACL231312 and ACL221326 and ACL231312. However, there were significant differences between the inbreds of ACL221402 and ACL231312 as well as ACL221402 and ACL221326. As for the diameter of the fruit, the thickness of the flesh, and the fruit total soluble solids, the inbred ACL221402 was found to be significantly different from the inbred of ACL211390, ACL231312, and ACL221326 and not significantly different from the inbred of ACL211390 and ACL231312, ACL211390 and ACL221326, ACL221402 and ACL231312 and ACL23131226 and ACL23131226. Furthermore, the fruit length shown in the 4 inbreds analyzed was not significantly different. The t-test results between the inbreds ACL211390, ACL221402, ACL221326, and ACL231312 showed significant to very significant differences in the yield characteristics of fruit weight, fruit diameter, flesh thickness, number of seeds, and fruit total soluble solids. The difference in the character of these results could be caused by differences in the composition of the genetic material between the inbreds ACL211390, ACL221402, ACL221326, and ACL231312. This is in accordance with the study of Huda et al.

(2017), which states that genotype has a significant effect on male flower age, harvest age, fruit length, fruit diameter, fruit flesh thickness, fruit skin thickness, fruit weight, and fruit total soluble solids.

Table 4. Results of the t-test character percentage.

Inbred	FW (g)	FD (cm)	FL (cm)	FFT (cm)	FTSS (^{o}Brix)
ACL211390 and ACL 221402	2.07ns	2.53*	0.57ns	2.63*	-3.97**
ACL211390 and ACL221326	-1.46ns	-1.31ns	0.24ns	0.73ns	0.41ns
ACL211390 and ACL 231321	-2.24*	-2.64*	-2.00ns	-1.98ns	2.21*
ACL221402 and ACL221326	-3.15**	-3.75**	-0.33ns	-3.70**	5.80**
ACL221402 and ACL231312	0.48ns	0.32ns	-1.09ns	1.03ns	-1.03ns
ACL221326 and ACL231312	1.63ns	1.33ns	-1.43ns	1.72ns	-1.60ns

Information: (*) *t*-value significant at 0.05, (**) *t*-value significant at 0.01 and (ns) *t*-value not significant. (WF) fruit weight, (FD) fruit diameter, (FL) fruit length, (FFT) fruit flesh thickness, (FTSS) fruit total soluble solids.

The main genotype characteristics or markers are those with high economic value such as fruit size, fruit weight, aroma, and sweetness. Fruit weight, shape, skin pattern, seed characteristics, sugar content, and other morphological traits are key markers in melon production that determine quality and market appeal. Higher weights often indicate larger yields, although mini melons are also in demand. The round or elliptical shape and the dark green stripe pattern on the rind are favored for their attractive appearance. Small to medium seed size is more common in commercial varieties due to ease of consumption. High sugar content, measured through the Brix index, is a key factor in fruit quality assessment. Other traits such as stem length and number of male flowers are also important in determining yield potential and genetic diversity (Akrami and Arzani, 2019; Lestari and Waluyo, 2022). However, it also needs to be understood that these expressions are influenced by many components, namely genotype, environment, and interactions between genotypes are factors that affect the diversity or differences in yield characters between inbreds (Hermanto et al., 2017).

Conclusion

The inbred strains ACL211390, ACL221402, ACL221326, and ACL231312 were able to accept both their own pollen and the pollen of the 5 inbred strains of the male parents. The percentage of pollination success between the combinations of inbred strains ACL211390, ACL221402, ACL221326, and ACL231312 showed varying values and was not 100% in all samples obtained. The differences in the success of the pollination methods (self-pollination and cross-pollination) were not significant, but the differences in fruit yield (fruit weight, fruit diameter, fruit length, fruit flesh thickness, and fruit total soluble solids) were higher in cross-pollination than in self-pollination with the same female inbreds. There were differences in phenotypic performance (fruit weight, fruit diameter, fruit length, fruit flesh thickness, and total fruit soluble solids) for some characters produced between inbred lines ACL211390, ACL221402, ACL221326, and ACL231312. The cross-pollination success rate and high fruit yield of genotypes ACL211390, ACL221402, ACL221326, and ACL231312 make them suitable as parents for hybrid production.

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EVALUACIJA PROIZVODNIH OSOBINA F3 INBRED LINIJA DINJE (*CUCUMIS MELO* L.) DOBIJENIH UNAKRSNIM OPRAŠIVANJEM I SAMOOPLODNJOM

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R e z i m e

Ovo istraživanje ima za cilj da utvrdi procenat oplodnje i proizvodne osobine nekoliko F3 inbred linija dinje dobijenih unakrsnim oprašivanjem i samooplodnjom. U istraživanju koje je sprovedeno 2021. i 2022. godine korišćen je rasad devet roditeljskih inbred linija dinje od kojih su 4 bile ženske (ACL211390, ACL221402, ACL221326 i ACL231312), a 5 muških (ACD211303, ACD211254, ACD221362, ACD231380 i ACL21402). Generalno, procenat uspešnosti oplodnje pokazao je različite vrednosti, a vrednost od 100% nije postignuta ni u jednom ispitivanoj kombinaciji. Ovo je bilo zbog toga što je oplodnja 3 hermafroditna cveta (ženski roditelj) na svakom uzorku bila izvedena u različitim vremenskim intervalima. Rezultati posmatranja proizvodnih osobina (masa ploda, prečnik ploda, dužina ploda, debljina mesa i ukupna rastvorena čvrsta materija ploda) pokazali su različite vrednosti između kombinacija oprašivanja kod istog ženskog roditelja. Izvori polena su odgovorni za razlike kod proizvodnih osobina između kombinacija oprašivanja sa istim ženskim roditeljem. Studentov t-test je pokazao da između inbred linija ACL211390, ACL221402, ACL221326 i ACL231312 (ženski roditelj) nije bilo značajnih razlika u prosečnom procentu uspešnosti oprašivanja, ali da su postojale značajne do veoma značajne razlike u nekoliko proizvodnih osobina. Razlike u proizvodnim osobinama bile su rezultat razlike u sastavu genetskog materijala između inbred linija ACL211390, ACL221402, ACL221326 i linije ACL231312.

Ključne reči: unakrsno oprašivanje, inbred linija, dinja, samooplodnja, oprašivanje.

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INOCULATION OF *ACINETOBACTER JOHNSONII* GY08 TO ENHANCE THE GROWTH OF FABA BEAN (*VICIA FABA* L.) UNDER DIFFERENT SALT CONCENTRATIONS

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Abstract: Abiotic stresses affect microbial populations and soil chemical and physical properties resulting in significant yield losses of several crops. An important environmental component that impacts plant growth and development from seed germination to maturity is salinity. The objective of this study was to examine the effect of inoculating salt-tolerant rhizobacteria on the morphological and physiological characteristics of faba bean under different salt concentrations in pot experiments. Eight rhizobacterial isolates were tested for their salt tolerance ability on nutrient agar. One best tolerant isolate with the best tolerance, which showed better growth at higher salinity, was selected and evaluated for its effect on the faba bean. The experiment comprised six treatments with three replications in a completely randomized design, and the data was analyzed using a one-way analysis of variance. The results showed that seed germination decreased by 4.16% and 8.33% at 150mM and 300mM salinity, respectively. However, the application of *Acinetobacter johnsonii* GY08 significantly enhanced seed germination by 4.16% and 6.38% with 150mM and 300mM salinity, respectively, compared to the uninnoculated treatments with the same salt concentration. Plants inoculated with *Acinetobacter johnsonii* GY08 showed higher biomass, shoot, and root elongation than the uninnoculated plants under both non-saline and saline conditions. The findings indicated that *Acinetobacter johnsonii* GY08 facilitated the growth of faba bean seedlings under salinity stress conditions and enabled them to thrive by accumulating more proline compared to uninnoculated plants. Therefore, further studies on various varieties and under field conditions are recommended.

Key words: salt tolerance, germination, rhizobacteria, pgpr.

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Introduction

Both genetic and environmental factors affect plant characteristics and their adaptation to different environments. Salinity is one of the environmental factors that influence plant growth and metabolism from seed germination to maturity (Kamran et al., 2020). The quantity of dissolved salts in the soil solution is known as soil salinity. It can be caused by either natural or artificial sources (Stavi et al., 2021). Salinity has the potential to reduce global food production by up to 30% (Machado and Serralheiro, 2017). Soil salinization affects an estimated one billion hectares worldwide, with an annual increase of two million hectares (Nasrallah et al., 2022).

Based on data from 118 countries covering 73% of the global land area, more than 4.4% of topsoil and more than 8.7% of subsoil are salt-affected (FAO, 2021a). It affects crop production in almost one-fourth of the world's cultivable land with about 1.5 million ha falling out of production each year (FAO, 2021b). It is estimated that about 5% of the land in Africa (Rome, 2015), and 19 million ha of land in sub-Saharan Africa are affected by salinity (Tully et al., 2015). Ethiopia has the largest area of salt-affected soils in Africa, due to both human activities and natural sources. The land affected by salinity in the country amounts to 11,033,000 hectares (Fikadu and Jemal, 2022).

High salinity in soil or irrigated water is a huge threat to yields since it negatively affects the morphology, physiology, and yield of crops via osmotic stress and ion toxicity. It causes a variety of physiological impairments in plants. For example, the decreased stomatal conductivity limits the C-fixation capacity, disrupting the catalytic activities of the enzymes that fix carbon and destroy the photosynthetic pigments (Ullah et al., 2021).

The faba bean (*Vicia faba* L.) is a widely cultivated crop in the highlands of Ethiopia, grown at elevations between 1800 and 3000 meters above sea level for multiple purposes (Misgana, 2017). In Ethiopia, faba beans cover about half of a million hectares of land, producing a total of 1.04 million tons and with a productivity rate of 2.1 tons/ha (Dereje and Debela, 2022). Despite its various benefits and the availability of high-yielding varieties (>3 t/ha) (MoALR, 2017), the national average yield of faba bean (2.11 t/ha) in Ethiopia has remained low compared to Egypt and the United Kingdom (3.47 and 3.83 t/ha, respectively) (CSA, 2018; FAOSTAT, 2018). This low productivity of the faba bean is caused by biotic and abiotic factors. Among the abiotic factors, soil salinity is a major limiting factor for faba bean production (Fekadu et al., 2018). Since faba bean is moderately sensitive to salinity, it should be grown in soils with low or no saline content. Several studies have shown that saline conditions are harmful to faba bean genotypes (Abd El-Baki and Mostafa, 2014; Bimurzayev et al., 2021).

Plants have developed various ways to protect themselves from salinity stress, including morpho-physiological and molecular responses (Zhao et al., 2021). On the other hand, saline soils can be improved through leaching, chemical application, drainage systems, and the use of organic compounds such as sewage sludge, compost, and manure (Orhan, 2021). Another effective and eco-friendly method to improve saline soils is by using salt-tolerant plants (halophytes) and microorganisms. This approach does not require any additional chemicals or materials to be added to the already salt-affected soil.

To meet the global food demands, it is crucial to find ways to enhance soil health and create strategies that are tolerant to salinity stresses, and other constraining factors, while maintaining normal plant growth. One recommendation that has gained relevance in the agriculture sector is the use of microbial communities as bioinoculants (Elanahal et al., 2022). Hence, the hypothesis of this research was that plant growth promoting rhizobacteria (PGPR) could enhance the growth of faba bean in saline soils by the production of growth hormones, exopolysaccharides and solubilizing inorganic phosphates.

Previous research has demonstrated that the use of halotolerant or halophilic bacteria in areas affected by salt can enhance plant productivity and soil fertility (Grover et al., 2021; Habib et al., 2016). Therefore, this study aimed to investigate the effect of salt-tolerant rhizobacteria inoculation on the morphological and physiological characteristics of faba bean under varying NaCl concentrations in pot experiments.

Material and Methods

The study was conducted at the University of Gondar, Department of Biology microbiology laboratory (Gondar town, Amhara Region, Ethiopia). For this study, we employed the high yielding Dosha variety of faba beans acquired from the Gondar Agricultural Research Center, Gondar, Ethiopia. A total of eight rhizobacterial strains with multiple plant growth-promoting traits were obtained from the collection established in our previous research (Gebeyehu et al., 2024) as indicated in Table 1.

Table 1. Rhizobacteria strains and their accession numbers.

No.	Strain name	Accession number
1	*Acinetobacter* sp. GY01	OQ248105
2	Bacterial strain GY02	OQ248106
3	*Acinetobacter johnsonii* GY03	OQ248107
4	*Chryseobacterium* strain GY04	OQ248108
5	*Chryseobacterium proteolyticum* GY05	OQ248109
6	*Pseudomonas costantinii* GY06	OQ248110
7	*Pseudomonas chlororaphis* GY07	OQ248111
8	*Acinetobacter johnsonii* GY08	OQ248112

Salt tolerance test

The rhizobacteria strains were tested for salt stress tolerance on nutrient agar supplemented with 2, 4, 6, 8, 10, and 12% levels of NaCl (w/v) according to Albdaiwi et al. (2020). The result was designated as positive (+) and negative (-) for the presence and absence of growth, respectively.

Effects of *Acinetobacter johnsonii* GY08 on seed germination and vigor index under different NaCl concentrations

Healthy faba bean seeds of the same size were selected and then surface-sterilized with 70% ethanol for 1 minute. Afterwards, they were rinsed with 5% sodium hypochlorite for 3 minutes and washed with 3 changes of sterile distilled water. *Acinetobacter johnsonii* GY08 was grown in a volumetric flask containing 50ml of nutrient broth at 30°C in an incubator shaker at 120 rpm for 48 hours. The culture pellets were separated from the supernatant by centrifugation at 8,000 rpm for 10 minutes (Eppendorf 5425G Centrifuge). The pellet was then diluted in normal saline (0.85% w/v NaCl) to give a final concentration of OD600 = 1.00 (10^8 cfu/ml). Surface-disinfected bean seeds were soaked in the cell suspension for 1 hour (Bal et al., 2013). The experiment consisted of 6 treatments with 3 replications in a completely randomized design. The treatments were as follows: control (faba beans irrigated with tap water) (T0); faba beans irrigated with 150mM salt (T1); faba beans irrigated with 300mM salt (T2); faba beans treated with GY08 and irrigated with tap water (T3); faba beans treated with GY08 and irrigated with 150 mM salt (T4); and faba beans treated with GY08 and irrigated with 300 mM salt (T5).

A total of 10 broad bean seeds per treatment were placed in 9-cm Petri dishes with two layers of moistened filter paper. To ensure sufficient humidity for germination, 5mL of sterile distilled water (T0 and T3), 5mL of 150 mM NaCl solutions (T1 and T4), and 5mL of 300 mM NaCl solutions (T2 and T5) were added to the Petri dishes every 2 days. The seeds were incubated at 28°C in an incubator. Germination was considered to have occurred when the radicle had reached half the length of the seed. The germination rate was recorded for 7 days. After 7 days, the root and shoot lengths were measured, and the germination rate and vigor index were calculated according to ISTA (1996):

Germination rate (%) = number of germinated seed / total number of seed ×100, Vigor index = (mean of root length + mean of shoot length) × % of seed germination.

Pot experiment

The experiment comprised 6 treatments as described in the previous section. There were three replicates of each treatment and a completely randomized design was applied. Seeds were prepared as described in the section above. Faba bean seeds were planted in plastic pots with a diameter of 25cm and a depth of 30cm. The pots were filled with 3kg of sterilized agricultural soil and arranged randomly. To ensure proper growth, the plants were irrigated with non-saline water for the first 21 days. After 21 days, each pot received 200ml of salt solution (150 and 300 mM NaCl) every two days for 40 days. The plants were harvested after 60 days, and morphological (shoot length, shoot fresh weight, shoot dry weight, root length, root fresh weight, and root dry weight) and biochemical parameters (chlorophyll and proline contents) were determined. The roots and shoots of the faba bean plants were excised with a sterile blade and weighed separately on an electronic balance to compute the fresh weight. The dry weight of the root and shoot was measured after oven-drying at 70°C for 72 hours (Toghueo et al., 2016).

To determine the chlorophyll content, the mature leaves of the treated faba bean were collected and one gram was measured for each treatment, then cut into fine pieces and crushed with a mortar and pestle. Following the method of Kamble et al. (2015), 5ml of 80% acetone was added and the mixture was carefully ground. After incubating for 3 hours at 4°C, the mixture was centrifuged at 8000rpm for 5 minutes (Eppendorf 5425G Centrifuge). The supernatant was transferred to a 50ml measuring cylinder, and the volume was increased to 20ml by adding 80% acetone. The absorbance of the solutions was measured at 663, 645, and 480nm using a spectrophotometer (Jenway 6405 Spectrophotometer), taking the 80% acetone solution as a blank. Readings were taken in triplicate samples and the average was used to calculate the chlorophyll content. The contents of chlorophyll a, b, and a + b (total chlorophyll) and carotenoids were calculated by applying the following formula (Arnon, 1949):

Chl.a= (12.7xA663)-(2.69xA645)/(1000xw)xv (mg/g),

Chl.b= (22.9xA645)-(4.68xA663)/(1000xw) x v (mg/ g),

Total chl. = (20.2 (A645) + 8.02 (A663)) / (1,001 x W) x v (mg/g), and

Carotenoids= (A480+0.114) (A663)-0.638 (A645)/ (1000xw) x v (mg/g),

where:

A = absorbance at a specific wavelength,

V = final volume of the chlorophyll extract in 80% acetone,

W = fresh weight of the tissue extracted.

The proline content was determined according to the method of Bates et al. (1973) using L-proline as a standard (Sigma-Aldrich). Firstly, 250 mg of leaves were homogenized in 5 ml of 3% 5-sulphosalicylic acid using a mortar and pestle.

Secondly, the homogenate was centrifuged at 8000 rpm for 20 minutes. Thirdly, the mixture of 1 ml of acid ninhydrin reagent, 1 ml of glacial acetic acid, and 1 ml of supernatant was incubated for 1 hour in a boiled water bath at 100°C, and the reaction was terminated by placing the mixture solution on ice for 10 minutes.

Finally, 2 ml of toluene was added to the mixture, and the absorbance of toluene was read at a wavelength of 520 nm using a visible spectrophotometer, with toluene serving as a blank. The serial concentrations of standard L-proline were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 µg/ml and their standard curve were made. Finally, the content of proline was determined from the standard curve of L-proline and its units were expressed as µmol g1 FW.

Statistical analysis

All data of faba bean growth parameters obtained from the plant growth promotion assay were analyzed by one-way ANOVA followed by the Tukey's test, with the bacterial inoculation method considered as an independent variable. All statistical analyses were calculated at the significance level $p \leq 0.05$ using SPSS software version 25.

Results and Discussion

Salt tolerance of the rhizobacterial strains

The results presented in Table 2 showed that the rhizobacterial strains exhibited a wide variation in their growth on the NA medium containing different concentrations of NaCl. Accordingly, all tested rhizobacterial isolates were tolerant to a concentration of 2–4% NaCl (w/v). Five strains were able to grow at a concentration of 6–10% NaCl. Only two rhizobacterial strains GY07 and GY08 survived at a salt concentration of 12% NaCl (w/v). *Acinetobacter johnsonii* GY08, which showed the best growth on nutrient agar supplemented with high NaCl content (12% w/v), was selected for this experiment. This isolate also showed multiple plant growth-promoting characteristics including phosphate solubilization, indole acetic acid (IAA), exopolysaccharide, and protease production. Salt-tolerant PGPR can help to alleviate soil salinity stress during plant growth, and bacterial exopolysaccharide (Astorga-Eló et al., 2021) can also help to alleviate salinity stress by lowering the amount of Na^+ available for plant uptake (Upadhyay et al., 2011).

Table 2. Salt tolerance of the rhizobacterial strains.

Isolate	NaCl concentrations (w/v)					
	2	4	6	8	10	12
Acinetobacter sp. *GY01*	+++	+++	++	+	+	-
Bacterial strain GY02	+++	++	++	+	-	-
Acinetobacter johnsonii GY03	+++	+++	+++	+	+	-
Chryseobacterium sp. strain GY04	+++	+++	+	+	-	-
Chryseobacterium proteolyticum GY05	+++	+++	+++	++	+	-
Pseudomonas costantinii GY06	+++	+++	+++	+	-	-
Pseudomonas chlororaphis GY07	+++	+++	+++	++	+	+
Acinetobacter johnsonii GY08	+++	+++	+++	+++	+++	++

Note: - = growth not detected, + = low growth, ++ = moderate growth, +++ = high growth.

Effects of *Acinetobacter johnsonii* GY08 on faba bean seed germination under different concentrations of NaCl

The result showed that exposure to salt adversely affected the germination of seeds and their vigor index values. However, the presence of *A. johnsonii* GY08 improved the germination and vigor index values of both salt-treated and untreated plants. The data in Table 3 indicated that seed germination decreased by 4.16% and 8.33% at salinity levels of 150mM and 300mM, respectively. On the other hand, inoculation with *A. johnsonii* GY08 significantly enhanced the germination percentage of seeds under both normal and salt-stressed conditions. The application of *A. johnsonii* GY08 increased seed germination by 4.16% and 6.38% at salinity levels of 150mM and 300mM, respectively, compared to the uninoculated treatments with the same salt concentration. These findings are consistent with previous research that indicates that PGPR can mitigate the negative effects of salinity on seed germination (Metwali et al., 2015; Ji et al., 2020). Seed germination and early seedling growth are the most salt-sensitive stages of plant growth under environmental stresses. This is because the seedling root is in direct contact with the soil and is affected by many soil changes, including salt stress. The use of PGPR promotes seed germination, which may be due to the ability of PGPR to synthesize hormones such as indole acetic acid, gibberellic acid, and cytokinins. These hormones regulate cell division and promote seed germination. The inoculation of *A. johnsonii* GY08 also improved the vigor index of both salt-treated and untreated seeds. The highest vigor index of 220.5±0.32 was recorded in T3, while the lowest vigor index was observed in T2 (63.36±0.12).

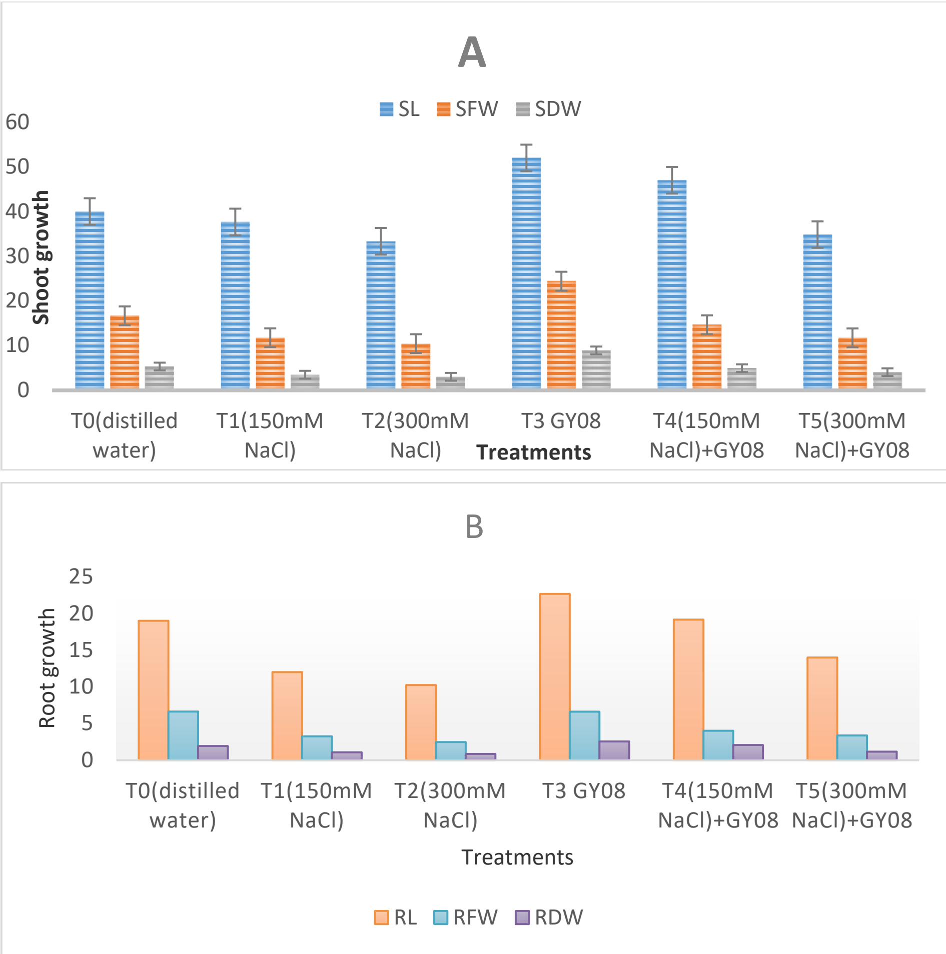
Table 3. Effects of *Acinetobacter johnsonii* GY08 on seed germination and vigor index in faba bean.

Treatment	Seed germination (%)	Vigor index
T0(distilled water)	96±0.01[ab]	175.68±0.21[b]
T1(150mM NaCl)	92±0.65[c]	102±0.11[c]
T2(300mM NaCl)	88±0.04[d]	63.36±0.12[d]
T3 GY08	98±0.5[a]	220.5±0.32[a]
T4(150mM NaCl)+GY08	96±0.32[ab]	166.08±0.13[ab]
T5(300mM NaCl)+GY08	94±0.21[bc]	159±0.43[bc]

Values are mean values ± standard deviation from three replicates. Different letters indicate a statistical difference between treatments (Turkey's test, $P < 0.05$) under normal and saline conditions.

Effects of *Acinetobacter johnsonii* GY08 on the growth parameters of faba bean under different concentrations of NaCl

The effect of *A. johnsonii* GY08 inoculation on faba bean growth was studied in both saline and non-saline soils. A significant ($p<0.05$) increase in the growth of faba bean inoculated with *A. johnsonii* GY08compared to control beans was found under both non-saline and saline conditions (Figure 1, Supplementary Table 1). Plants inoculated with *A. johnsonii* GY08 showed higher biomass, shoot, and root elongation compared to uninoculated plants under both non-saline and saline conditions. The highest growth increase in all growth parameters was recorded in T3 (52$\pm$0.23cm), while the lowest growth increase in all growth parameters was observed in T2 (33.33$\pm$0.09cm) (Figure 1 and Supplementary Table 1). These findings align with those reported by Metwali et al. (2015), who found that faba bean plants treated with *P. fluorescens*, *B. subtilis*, and *P. putida* exhibited significant growth stimulation as reflected in length, shoot fresh weight, and leaf area. The inoculation with *A. johnsonii* GY08 increased growth parameters in the presence of salinity stress and this may be attributed to the ability of PGPR to limit Na+ and Cl^- transport into the shoots (Hmaeid et al., 2019). Similarly, Singh and Jha (2016) reported that inoculation of salt-tolerant PGPR under salt stress increased plant growth and yield. Thus, the PGPR strain *A. johnsonii* GY08 can be regarded as a promising microorganism for the formulation of biofertilizers especially suitable for saline soils to minimize faba bean crop yield reduction caused by soil salinization. *A. johnsonii* could be a potential plant growth promoting bacterium that produces indole-like compounds, exopolysaccharide and different hydrolysis enzymes and helps in nutrient solubilization and mobilization (Bhattacharya et al., 2024, Gebeyehu et al., 2024).



Note: SL – shoot length, SFW – shoot fresh weight, SDW – shoot dry weight, RL – root length, RFW – root fresh weight, RDW – root dry weight.

Figure1. The effect of *Acinetobacter johnsonii* GY08 on the morphological growth parameters of faba bean (A, shoot; B, root) under different NaCl concentrations.

Effects of the inoculation with *Acinetobacter johnsonii* GY08 on the photosynthetic pigments of faba bean plants under controlled and salt-stressed conditions

Plants exposed to salt stress exhibited a significant decrease in their photosynthetic pigments, including chlorophyll a, chlorophyll b, and carotenoids. However, plants inoculated with *A. johnsonii* GY08 showed increased photosynthetic pigments compared to the control plants under both saline and non-saline conditions (Figure 2). The plants treated with *A. johnsonii* GY08 and subjected to salt stress showed the highest chlorophyll contents, including chlorophyll a, chlorophyll b, and carotenoids, which were recorded at T3 (Figure 2 and Supplementary Table 2). This result is consistent with the findings of Yildirim et al. (2008), who reported that bacterial inoculants led to a significant increase in shoot/root dry weight, leaf number per plant, relative water content of the leaf, and chlorophyll content of the radish fruit.

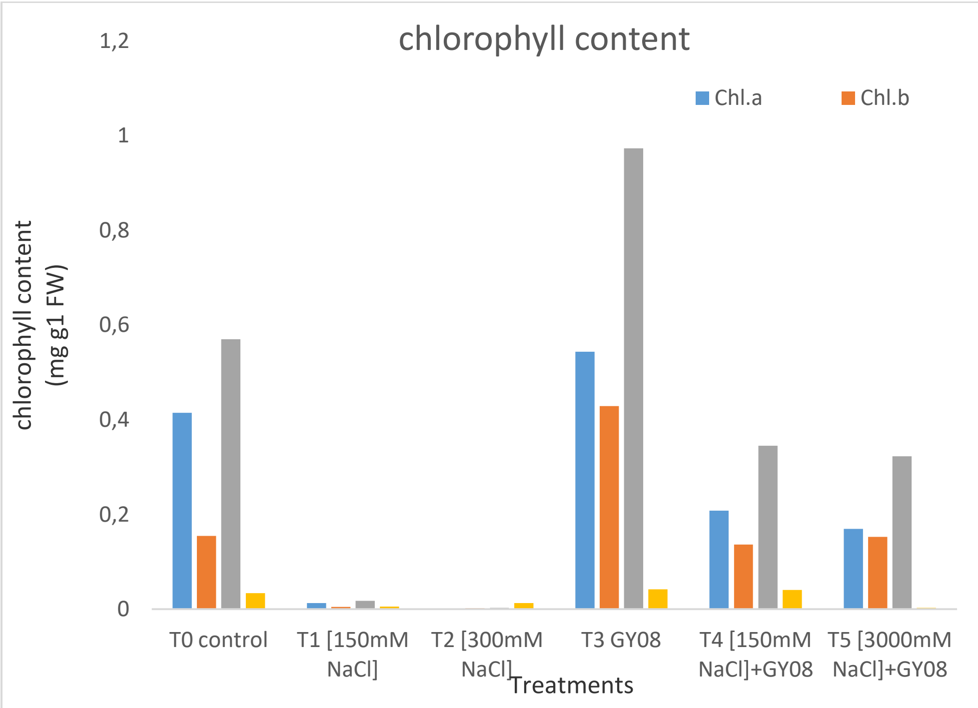


Figure 2. Effects of the inoculation with *Acinetobacter johnsonii* GY08 on the photosynthetic pigments of faba bean plants under controlled and salt-stressed conditions.

Effect of *Acinetobacter johnsonii* GY08 on osmolytes accumulation: proline content

The proline concentration (ug g1 FW) increased in the leaves of the salinity-stressed plants as compared to the control plants. In this context, T5 (300 mM NaCl +GY08) recorded the highest value of proline content. The minimum value was recorded in the control pot treated with distilled water only. We observed that the accumulation of proline was increased in all inoculated and uninoculated plants under salinity stress conditions compared to the corresponding non-saline plants (Figure 3 and Supplementary Table 2). This supports the previous finding of Metwali et al. (2015) that rhizobacterial inoculation in faba bean increases the accumulation of proline. The inoculated plants had higher proline content than the uninoculated plants. The results of the current study suggest that proline content played an active role in defense responses and was upregulated by PGPRs. Salt stress causes a decrease in water uptake efficiency, leading to an imbalance in osmotic pressure and apoptosis. Proline acts as a compatible osmolyte, attempting to counteract the effects of salt stress (Albdaiwi et al., 2020).

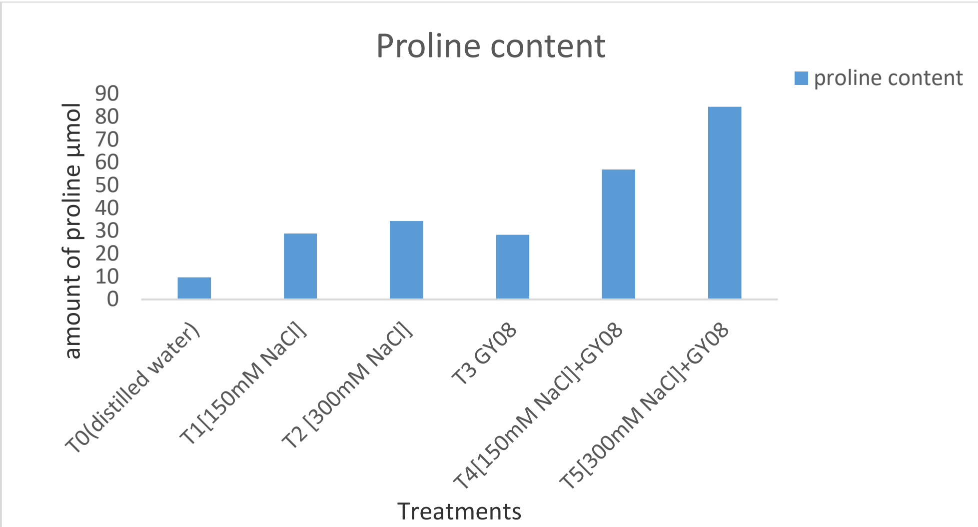


Figure 3. The effect of the inoculation with *Acinetobacter johnsonii* GY08 on the proline content of faba bean plants under controlled and salt-stressed conditions.

Conclusion

The results of the present study suggest that the rhizobacterial isolate *Acinetobacter johnsonii* GY08 facilitated the growth of faba bean seedlings under salinity stress conditions in the Dosha variety and allowed them to thrive. *Acinetobacter johnsonii* GY08 possesses a great potential to increase crop productivity and its association could reduce the negative impacts of salinity. Several field trials with different varieties under various field conditions are recommended for further utilization of this isolate as an option for salt stress management.

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POBOLJŠANJE RASTA BOBA (*VICIA FABA* L.) PRI RAZLIČITIM KONCENTRACIJAMA SOLI INOKULACIJOM SA *ACINETOBACTER JOHNSONII* GY08

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R e z i m e

Abiotski stresovi utiču na mikrobiološke populacije i hemijska i fizička svojstva zemljišta, što rezultira značajnim gubicima prinosa useva. Važna komponenta životne sredine koja utiče na rast i razvoj biljaka, od klijanja semena do zrelosti, je salinitet. Cilj ovog rada je bio da se ispita uticaj rizobakterija tolerantnih na povišen sadržaj soli na morfološke i fiziološke karakteristike boba pri različitim koncentracijama soli. Testirano je osam izolata rizobakterija kako bi se utvrdila njihova sposobnost tolerancije povišenog sadržaja soli u hranljivom agaru. Izolat koji je pokazao najbolji rast pri visokom salinitetu je odabran i procenjeno je njegovo dejstvo na rast boba. Eksperiment je obuhvatio šest tretmana sa tri ponavljanja u potpuno slučajnom dizajnu, a podaci su analizirani korišćenjem jednosmerne analize varijanse. Rezultati su pokazali da je klijanje semena smanjeno za 4,16% i 8,33% pri salinitetu od 150 mM odnosno 300 mM. Međutim, primena *Acinetobacter johnsonii* GI08 značajno je poboljšala klijanje semena za 4,16% odnosno 6,38% pri salinitetu od 150 mM odnosno 300 mM, u poređenju sa tretmanima koji nisu inokulisani, a imali su istu koncentraciju soli. Biljke inokulisane sa *Acinetobacter johnsonii* GI08 pokazale su veću biomasu, izduženje izdanaka i korena u poređenju sa biljkama koje nisu inokulisane u uslovima sa i bez povećane koncentracije soli. Rezultati su pokazali da je *Acinetobacter johnsonii* GI08 olakšao rast klijanaca boba u uslovima stresa saliniteta i omogućio im da napreduju akumulacijom većih količina prolina, u poređenju sa neinokulisanim biljkama. Stoga, se preporučuju dalja istraživanja na različitim sortama i u poljskim uslovima.

Ključne reči: tolerancija na so, klijanje, rizobakterije, PGPR.

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CHEMICAL AND TECHNOLOGICAL COMPOSITION OF SPRING GREEN PEA (*PISUM SATIVUM* VAR. *HORTENSE* L.) GENOTYPES

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Abstract: Through the chemical-technological analysis of (technologically) mature spring pea genotypes, we examined the following traits: moisture content, ash, oil, total nitrogen, protein, total sugars, starch, cellulose, and content of total soluble solids (Brix) (eight lines and two varieties). This research aimed to determine the chemical and technological characteristics of the selected spring pea genotypes, assess the variability structure of pea genotype characteristics, and therefore assess the contribution of the individual characteristics to the overall variability. The field trial was set up in 2022 at the Rimski Šančevi site on a chernozem-type soil in an irrigation system in the Department of Vegetable and Alternative Crops, Institute of Field and Vegetable Crops, Novi Sad. The lines with a higher protein content SK-1, SK-5, and SK-10 as well as the lines with a higher sugar content SK-4, SK-5, and SK-8, which are included in the development of pea varieties, have a special value in the selection of vegetable peas with a high protein and sugar content. Pea genotypes SK-6, SK-7, and SK-8 with a higher Brix value can be used for the earlier selection of sweeter peas suitable for fresh or early spring consumption. Based on the cluster analysis, the pea genotypes were classified into individual groups to assess the impact on the variability of each trait. Principal component analysis revealed that the four separate components cumulatively explained 91.91% of the total variability.

Key words: garden pea, seeds, PCA, cluster.

Introduction

Spring green pea (*Pisum sativum* var. *hortense* L.) is an annual cool-season herbaceous legume that belongs to the *Fabaceae* family. It is one of the nutritionally most important vegetable crops, as it contains a high percentage of proteins, essential amino acids, and a significant content of vitamins, minerals, and

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carbohydrates. The rapid growth of the world's population today also requires an increase in food supply (Červenski et al., 2021; Tamindžić et al., 2023). In this regard, peas are rich in proteins (20–35%), sugars (8–12%), low amounts of fat (0.5–4.0%), and high amounts of starch (about 30–48%), vitamins A and C, calcium and phosphorus and a small amount of iron (García Arteaga et al., 2021; Kumar et al., 2021).

Peas are one of the most widely produced legumes, accounting for 26% of the total global production of legumes. As a leguminous crop, peas fix nitrogen in the soil and are thus also beneficial in agriculture (Červenski et al., 2017). It is also one of the most commonly consumed and cultivated legumes (Shen et al., 2022). With the change in people's dietary habits, the availability of garden peas in the market is demanded by customers throughout the year. In addition to the seasonal use of fresh grain, it is also consumed as a processed product, whether canned, dehydrated or frozen for off-season consumption (Nasir et al., 2023). Regarding the importance and quantity of processed products, peas occupy one of the first places in the vegetable canning industry (Đorđević et al., 2021). Pea production has a long tradition as an industrial crop in Serbia. Short growing seasons, relatively simple production, pleasant taste, and high nutritional value of the grain stimulate the production and consumption of peas. It has a nutritionally favorable composition concerning macronutrients: low fat, high fiber and protein content, and starch with a low glycemic index (Jovićević et al., 2008). The fact that the energy value of peas is 339 kJ shows the importance of this crop for human nutrition (Vlahović, 2015).

This research aimed to determine the chemical and technological properties of the selected spring green pea genotypes, look into the structure of the variability of the characteristics of the pea genotypes, and assess the contribution of the individual characteristics to the total variability.

Material and Methods

Study area

The field trial was set up in 2022 at the Rimski Šančevi site on a chernozem-type soil in an irrigation system in the Department of Vegetable and Alternative Crops, Institute of Field and Vegetable Crops, Novi Sad (45°19'55.7"N, 19°50'14.9"E, and 86 masl).

The experiment was conducted using a randomized block design with five replications. The basic plot comprised two rows of pea genotypes spaced 20 cm apart between the rows and 5 cm apart within the rows, with a row length of 3 meters. The distance between the two plots was 80 cm to facilitate manipulation and tillage between the rows during the growing season. Harvesting was done manually at the time of technological maturity of all examined pea genotypes.

Sampling procedure

Under favorable conditions, the phase of optimal technological maturity usually lasts from 2 to 5 days, depending on the variety. Harvesting is carried out when 75% to 80% of the peas are technologically ripe, which is characterized by a sweet taste, uniform color, uniform consistency and characteristic smell. These organoleptic quality parameters correspond to the optimal content of dry matter, a certain ratio of sugar and starch, the amount of alcohol-insoluble substances (ANS) and grain hardness. Compliance with these quality parameters is achieved with a sugar content of 5.5 to 6.5, a starch content of 6% to 7%, and a content of nitrogenous substances of around 5%. This ratio of the main ingredients is achieved when the dry matter amounts to 16 to 22%, depending on the pea variety (Vračar, 2001; Ilić et al., 2007; Jovićević et al., 2008; Červenski et al., 2021).

Plant material

The examined material is part of the genetic collection of *Pisum sativum* L., which belongs to the Institute of Field and Vegetable Crops, Novi Sad. Eight pea lines and two commercial spring green pea cultivars, Tamiš (ST) and Danube (SD) were included in this research. The tested spring green pea genotypes were selected based on previous studies/observations and the determination of specific parameters important for pea breeding.

Measurements

The working sample for the chemical and statistical analyses consisted of 10 plants per replication, i.e., a total of 50 plants per genotype. Fresh pea seeds were homogenized (using IKA T 10 basic ULTRA-TURRAX®) and further used for the analyses of the contents of ash, proteins, oil, cellulose, starch, total sugars, Brix (Bx). Moisture and ash contents were determined gravimetrically (dried for 3 h at 105°C and ignited for 2 h at 600°C) according to Ph. Eur. (2013). Total nitrogen was determined using the Kjeldahl method (manufacturer's specification Gerhardt, 2003), while total protein content was calculated using the conversion value of 6.25. The oil content was determined by the Soxhlet extraction (8 h, 70°C) (Ph. Eur., 2013). The cellulose content was determined by the modified Scharrer method (SRPS ISO 6541:1996) (identical to ISO 6541:1981). The starch content was determined by the polarimetric method (ISO 10520:1997). Total sugar was determined according to the Luff-Schoorl method (Official Gazette, 41/87). All seed traits were expressed as g per 100 g of the dry weight (g 100 g^{-1} d.w.) and moisture content (%). The Balling Relative Intensity Index (Brix, °Bx), the sugar content of an aqueous solution (g sucrose/100 g of the sample), was determined directly using a digital refractometer (ATR ST Plus, Schmidt + Haensch, Germany) and expressed as % of the fresh pea seeds.

Statistical analysis

The basic statistical indicators for quantitative traits were calculated using the InfoStat ver. 2011 program. The following values were determined: minimum, maximum, mean values, and coefficient of variation. The Jamovi 2.3.24 software was used for cluster analysis (CA) and principal component analysis (PCA) to group the genotypes based on similarities and differences in quantitative traits. For CA, the Euclidean distance measure and the complete clustering method were used as options in the snow cluster module. For the component loadings, no rotation method was selected in the factor module, and the snow cluster module was used for the PCA biplot.

Results and Discussion

Botanically mature grain has a low water content and a higher energy value and is a significant source of protein in the diet (Červenski et al., 2021). Peas are essential for human nutrition due to their high protein, sugar and starch content and high energy value. As the grain ripens, the content of sugar and peptides decreases, the content of protein and starch increases, and the grain becomes firmer, with higher tenderometric values and therefore becomes unfavorable for all forms of processing. As the degree of maturity increases, the sugar is transformed into starch and the grain acquires a harder consistency and a floury taste and is less acceptable. Considering that the pea grain is of better quality when the sugar content is higher, great attention is paid to the degree of maturity (Jovićević et al., 2008).

Seeds play a crucial role in creating optimal yield through pathogen-free crop production. Healthy seeds, free from seed-transmitted pathogens, are a prerequisite for successful production and an optimal plant population (Milosević et al., 2023).

The values of the analyzed traits of the tested spring green pea genotypes are listed in Table 1.

Moisture content in spring green pea seeds

The moisture content of the green pea genotypes in this research ranged from a minimum of 61.31% (SK-6) to a maximum of 72.22% (SK-5) (Table 1). These values are slightly higher compared to the results of Borah et al. (2021), who stated that the moisture content ranged between 58.51% and 62.31%. Research by Ganjloo et al. (2018) has found that the initial moisture content of green peas is up to 75.15%. They also state that all physical properties of green pea seeds depend on moisture content. Hatamipour and Mowla (2003) note that green peas have a natural moisture content of about 75%. The variation of moisture content of green peas in the range from 71.25% to 79.2% was obtained in the study of Senapati et al. (2019).

Table 1. Values of chemically and technologically analyzed contents of ash, proteins, oil, cellulose, starch, total sugars, Brix expressed as g per 100 g of the dry weight (g 100 g^{-1} d.w.) and moisture content (%) of fresh (a) and dry (b) seeds.

Pea genotype	Moisture content[a]	Ash[b]	Oil[b]	Total nitrogen[b]	Proteins[b]	Total sugars[b]	Starch[b]	Cellulose[b]	Brix[ad]
ST	64.98	3.67	7.58	5.03	31.43	8.32	48.87	15.21	17.6
SD	64.55	3.38	6.99	3.99	24.96	8.58	53.20	10.17	16.5
SK-1	70.80	3.75	10.11	4.57	28.55	6.51	53.69	9.94	11.9
SK-4	69.11	3.93	8.99	3.68	22.97	13.15	41.89	6.79	14.5
SK-5	72.22	3.84	7.23	4.78	29.89	12.80	48.63	8.82	12.6
SK-6	61.31	3.43	3.91	3.43	21.44	5.28	56.80	9.54	16.0
SK-7	62.28	3.44	6.67	4.06	25.36	5.02	63.38	8.12	16.7
SK-8	66.38	3.59	7.39	4.11	25.70	11.38	38.63	9.28	17.6
SK-9	67.64	3.67	14.60	3.59	22.43	6.10	47.17	18.31	15.4
SK-10	63.43	3.62	8.62	4.29	26.80	5.68	35.98	10.20	15.8
Mean	66.27	3.63	8.21	4.15	25.95	8.28	48.82	10.64	15.4
Minimum	61.31	3.38	3.91	3.43	21.44	5.02	35.98	6.79	11.9
Maximum	72.22	3.93	14.60	5.03	31.43	13.15	63.38	18.31	17.6
CV[c]	5.48	4.94	33.88	12.58	12.58	37.78	17.24	32.56	12.4

Coefficient of variation (%),[d] (°Bx).

Ash content in spring green pea seeds

Ash content is a raw parameter, which is considered an indicator of the mineral content in the edible part of the grain, which includes essential elements for human life (Mohammed et al., 2018). As for this parameter, the values varied between genotypes. The lowest value of ash content was recorded in the Dunav variety (SD) at 3.38 g $(100\ g)^{-1}$, in the pea line SK – 4 g $(100\ g)^{-1}$, and the ash content was 3.93 g $(100\ g)^{-1}$ (Table 1). According to previous literature reports, the ash content in peas varied and ranged from 2.3 to 5.2 g $(100\ g)^{-1}$ (Wang and Daun, 2004; Boye et al., 2010; Nikolopoulou et al., 2007; Wendy et al., 2012; Piecyk et al., 2012; Wani and Kumar, 2014; Jadwisieńczak et al., 2014; Červenski et al., 2017).

Oil content in spring green pea seeds

There were significant differences between green pea genotypes in terms of fatty oil content. The value of fatty oil content ranged from 3.91 (SK-6) to 14.60 g $(100\ g)^{-1}$ (SK-9) (Table 1). The tested genotypes had a significantly higher fatty oil content compared to literature data, indicating that the fatty oil content in peas ranges from 0.6 to 3.95 g $(100\ g)^{-1}$ (Wang and Daun, 2004; Nikolopoulou et al., 2007; Boye et al., 2010; Wendy et al., 2012; Pratap and Kumar, 2011; Piecyk et al., 2012; Wani and Kumar, 2014; Jadwisieńczak et al., 2014; Červenski et al., 2017). When analyzing 96 different pea samples, Hacisalihoglu et al. (2020) obtained a variation in the oil content in the grain of 5.7–21.4 g (100 g)$^{-1}$, which indicates peas with an extremely high oil content. They stated that several studies had discussed the value of developing peas as a low-cost oilseed for cultivation in colder climates, such as Canada and Northern Europe. Peas have a lower oil content (<40 g (100 g)$^{-1}$) compared to other legumes such as soybean, which has an average oil content of 200 g (100 g)$^{-1}$. Screening of potentially high-value lines such as the SK-9 line based on oil content can be used in selection to produce pea varieties with a high oil content.

Total nitrogen and protein contents in spring green pea seeds

The total nitrogen content in our research ranged between 3.43 g (100 g)$^{-1}$ (SK-6) and 5.03 g (100 g)$^{-1}$ (SD) (Table 1). These results are in agreement with Urbano et al. (2005), Gvozdenović et al. (2011), Červenski et al. (2017) and Borah et al. (2021), who have stated that the total nitrogen content ranges up to 4.49 g (100 g)$^{-1}$. The increase in the total nitrogen content can be due to temperature and water conditions as well as morphological and useful characteristics that are subject to change by breeding (Gautam et al., 2017).

Proteins are essential macronutrients and an important part of a healthy diet. High-quality pea proteins are a significant source of essential amino acids such as histidine, lysine, phenylalanine, and threonine (Gomes et al., 2021). Peas are increasingly used as a protein source in plant-based products (García Arteaga et al., 2021). Increasing attention is being paid to plant proteins due to the growth of the world's population, the growing protein deficiency, and their diverse ecological, functional, nutritional, and health benefits (Shen et al., 2022).

The values of protein content in our research ranged from 21.44 g (100 g)$^{-1}$ (SK-6) to 31.43 g (100 g)$^{-1}$ (SD) (Table 1). A review of the previous literature revealed that the protein content in pea seeds ranged between 15.8 g (100 g)$^{-1}$ and 34.7 g (100 g)$^{-1}$ (Wang and Daun, 2004; Stanek et al., 2004; Nikolopoulou et al., 2007; Boye et al., 2010; Pratap and Kumar, 2011; Wendy et al., 2012; Piecyk et al., 2012; Wani and Kumar, 2014; Jadwisieńczak et al., 2014; Sepehya et al., 2015; Khichi et al., 2017; Barcchiya et al., 2018; Singh and Dhall, 2018; Červenski et al., 2017; Borah et al., 2021), which is in agreement with our results. The overall phenotypic expression of protein content depends on environmental and genotypic components, and cultivars originating from different geographical areas manifest a range of protein content levels (Dhaliwal et al., 2021).

Total sugar content in spring green pea seeds

When harvested as a young grain, while the endosperm is still soft, peas are rich in vitamins and sugars. This phase of development is relatively short, and the higher production of young grains is achieved by successive sowing of the same pea cultivar or simultaneous sowing of pea cultivars with different vegetation periods (Ambrose, 2008).

In this research, a significant variation in the content of total sugar was observed between the tested pea genotypes (Table 1). The values of the total sugar content ranged between 5.02 g (100 g)$^{-1}$ for SK-7 and 13.15 g (100 g)$^{-1}$ for SK-4. The range of total sugar content from 0.7 g (100 g)$^{-1}$ to 28.59 g (100 g)$^{-1}$ has been established in the literature (Wang and Daun, 2004; Urbano et al., 2005; Nikolopoulou et al., 2007; Pratap and Kumar, 2011; Wendy et al., 2012; Jadwisieńczak et al., 2014; Sepehya et al., 2015; Červenski et al., 2017; Singh and Dhall, 2018; Borah et al., 2021).

Starch content in spring green pea seeds

Starch makes up about 45–50 g (100 g)$^{-1}$ of the dry weight of pea seeds and consists of several fractions, which are usually classified according to their structure and digestibility (Robinson and Domoney, 2021). The pea genotypes used in this research included lines that produce seeds with different starch content. According to the obtained results, the starch content in this research ranged from a minimum of 35.98 (SK-10) to a maximum of 63.38 g (100 g)$^{-1}$ (SK-7) (Table 1), which is similar to previous findings (Wang and Daun, 2004; Urbano et al., 2005; Nikolopoulou et al., 2007; Pratap and Kumar, 2011; Wendy et al., 2012; Piecyk et al., 2012; Sepehya et al., 2015; Červenski et al., 2017; Borah et al., 2021). Pea starch is commonly used in the diet due to its relatively low degree of digestibility and high content of resistant starch, and thus these results are of great importance.

Cellulose content of spring green pea seeds

As for the cellulose content, the values in this research ranged from a minimum of 6.79 (SK-4) to a maximum of 18.31 g (100 g)$^{-1}$ (SK-9) (Table 1). According to the literature sources, the cellulose content varied among the pea cultivars and ranged between 2.0 and 15.0 g (100 g)$^{-1}$ (Wang and Daun, 2004; Stanek et al., 2004; Boye et al., 2010; Pratap and Kumar, 2011; Wendy et al., 2012; Wani and Kumar, 2014; Jadwisieńczak et al., 2014; Shen et al., 2022). The SK-9 line had the highest cellulose content, which ranks it among the peas with increased fiber content compared to the literature data. According to the recommendation of Dodevska et al. (2013), green peas have great potential for medical nutrition therapy that requires a higher fiber intake as they are an excellent source of total dietary fiber.

Brix

The sugar content, of course, influences sweetness, an important component of product quality. However, sugar is the most abundant soluble solid in many vegetable juices. Therefore, Brix values primarily represent estimates of the sugar content in vegetables. Nevertheless, it is important to note that sweetness can be overwhelmed by other aspects of flavor. Therefore, a high Brix value does not guarantee a sweet flavor (Ahmed et al., 2022). The content g (100 g)$^{-1}$ of total soluble solids (or Bx) in spring green peas indicates the possibility of selecting the appropriate source material for crop improvement. The tested genotypes showed a significant variation in total soluble solids in spring green peas. The pea line SK-1 had a minimum of 11.9 g (100 g)$^{-1}$, while the maximum values of total soluble solids were recorded in SK-8 and ST – 17.6 g (100 g)$^{-1}$ (Table 1). Previous studies have also found a significant difference in total soluble solids between different cultivars, with Brix values ranging from 6.81 to 25.33 g (100 g)$^{-1}$ (Sepehya et al., 2015; Khichi et al., 2017; Barcchiya et al., 2018; Borah et al., 2021; Gautam et al., 2017; Sharma et al., 2020; Yathish et al., 2021; Arunadevi et al., 2022).

Statistical analysis of the tested quality parameters of spring green pea seeds

Ash and moisture contents were the traits with the lowest coefficient of variation (4.94% and 5.48%, respectively), which could indicate a low selection gain for ash content in future generations, while the low moisture content showed that the genotypes were similar in terms of maturity date and the samples were taken at the same time for analysis (Table 1). The high coefficient of variation was noted for total sugar (37.78%), oil (33.88%), and cellulose content (32.56%), indicating high variability among genotypes for these traits.

Table 2. Principal component analysis of the studied traits.

Trait	PC 1	PC 2	PC 3	PC 4
Moisture	0.933			
Ash	0.905			
Oil	0.402	-0.805	0.340	
Total nitrogen	0.560	0.603	0.561	
Proteins	0.560	0.603	0.561	
Total sugars	0.668		-0.476	0.385
Starch	-0.444			-0.748
Cellulose		-0.544	0.771	
Brix	-0.660			0.665

*Values below 0.3 are not shown.

The principal components analysis reduced the original eight variables to four artificial, uncorrelated variables, i.e., the principal components. The principal component method concentrated the variability on the first principal component. The first principal component explained most of the variability of all the investigated properties. The first component was mainly defined by the following properties: moisture, ash, and total sugars. The second component had the highest correlation with fatty oil, total nitrogen, and protein content. The cellulose content was defined as the third component. The fourth component consisted of starch and Brix (Table 2).

The four extracted components cumulatively explained 91.9% of the total variability. The individual contribution of each of the mentioned components to the total variability was 39.54 %, 20.42%, 18.38% and 13.56 %, respectively (Table 3).

Table 3. Eigenvalue and percentage of variance using four principal components (PCs).

PC	Eigenvalue	Total variance, %	Cumulative, %
1	3.5589	39.54	39.54
2	1.8376	20.42	59.96
3	1.6545	18.38	78.34
4	1.2210	13.56	91.90

In this regard, by analyzing the chemical composition of winter pea grains, the authors (Shen et al., 2022) obtained three separate components, which collectively explained 81.59% of the total variability. Moreover, the results of Espósito et al. (2007) obtained for pea genotypes for the first two components explained 67.7% of the variability in the first trial season and 69.8% of the variability in the second trial season.

The factor loading > 0.70 was used as a criterion for extracting the variables that defined most of the extracted components. The factor loadings are correlations between the individual variables and factors that indicate the degree of correspondence between the variables and the factors.

Based on the cluster analysis, the genotypes were divided into four individual groups. The first observed group of spring pea genotypes (SK-10, SK-8, ST) had four maximum values among the observed properties, namely: total nitrogen content (ST), protein (ST) and Brix (ST and SK -8). In this group, one of the lowest values of the observed properties was recorded for the starch content (SK-10 and SK-8). The contents of moisture, ash, oil, and total sugars were mainly around the average value determined for the observed properties (Figure 1).

The second group of spring pea genotypes (SK-9) was obtained by separating the mentioned genotypes from the others based on the highest content of oil and cellulose. The values of the other properties were around the observed average values, although they were mostly slightly less than the arithmetic mean of the observed properties (Figure 1).

In the third group of spring green pea genotypes (SK-7, SD, SK-6), the highest value among the observed genotypes was obtained only for starch content (SK-7). The minimum values of the examined traits of the pea genotypes defined this group, such as moisture (SK-6, SK-7), ash (SD, SK-6, SK-7), oil (SK-6, SK-7, SD), total nitrogen (SK-6), protein (SK-6), and total sugar contents (SK-7, SK-6). The cellulose content was slightly lower than the arithmetic mean value, while the Brix values were a bit higher than the arithmetic mean of the observed pea genotypes.

In the fourth group of spring green pea genotypes (SK-5, SK-1, SK-4), maximum values were obtained for the contents of moisture, ash, and total sugars (SK-4 and SK-5). SK-4 achieved the minimum value for the cellulose content, while all three genotypes had the minimum values for the Brix property. Other trait values for this group were around the arithmetic mean of the individual properties (Figure 1).

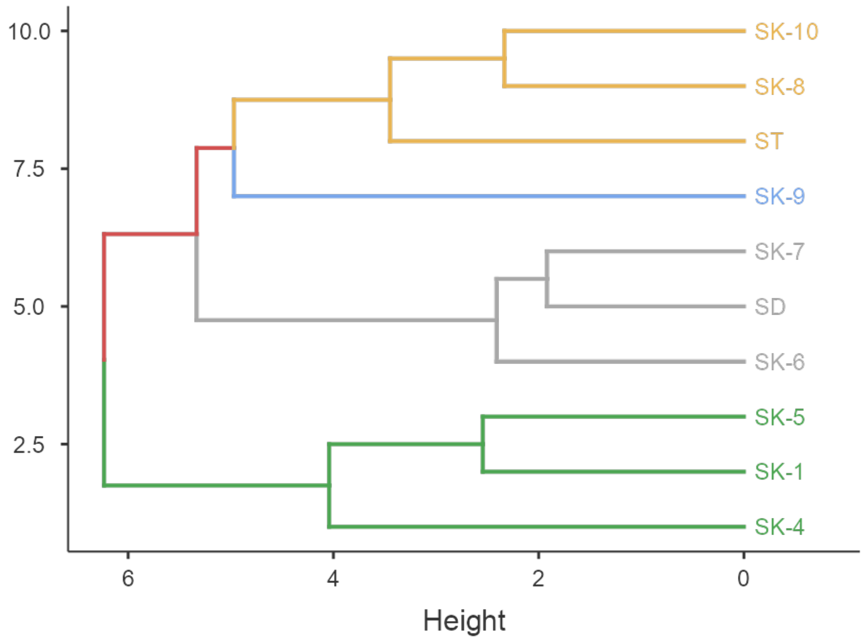

Figure 1. The cluster dendrogram of the studied spring green pea genotypes.

The PCA-biplot summarized the arrangement of the properties and the tested pea genotypes based on the PC analysis.Thus the connection between the observed properties and the pea genotypes can be seen based on the highest % of the explained variance of the first two main components (Figure 2).

The lower left quadrant of the PCA-biplot graph is defined by the highest cellulose content of the pea genotype SK-9, and therefore this genotype is separated into a separate group on the dendrogram (Figure 2).

The upper left quadrant of the PCA-biplot graph is defined by the pea genotypes SK-6, SK-7, and SD. SK-7 had the highest starch content value. The contents of ash, oil, and moisture are the furthest away from the mentioned genotype group because they achieved the minimum values of these properties (Figure 2).

The group of genotypes SK-1, SK-4, and SK-5 achieved maximum values for moisture content, ash, and total sugars, which is why they are located at a corresponding distance on the graph (Figure 2).

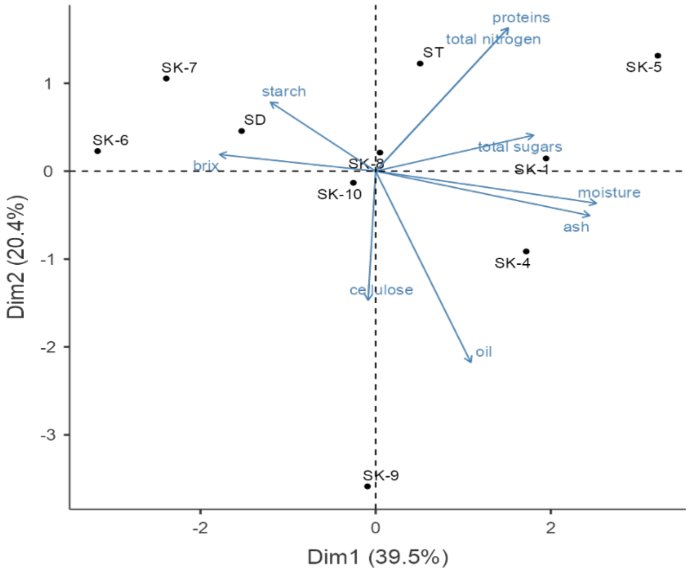

Figure 2. The PCA-biplot graph of the studied spring green pea genotypes.

Conclusion

This research aimed to determine the chemical and technological characteristics of the selected spring green pea genotypes. Through the chemical-technological analysis of the (technologically) mature spring pea genotypes, we examined the following traits: moisture content, ash, oil, total nitrogen, protein, total sugars, starch, cellulose and Brix. The tested pea genotypes were better studied and grouped according to the aforementioned analysis.

The lines with a higher protein content SK-1, SK-5 and SK-10, as well as the lines with a higher sugar content SK-4, SK-5 and SK-8, which are included in the development of pea varieties, will have a special value in the selection of vegetable peas with a high protein and sugar content.

The pea genotypes SK-6, SK-7 and SK-8 with a higher Brix can be used for an earlier selection of high sugar peas suitable for fresh, i.e., early spring consumption.

The research results have confirmed that the use of Brix in the selection of vegetable peas is mainly an indicative value for the assessment of the sweetness of the fresh grain of the lines. Using principal component analysis, four separated components explained a total of 91.912% of the total variability. The first component was defined to the greatest extent: the content of moisture, ash and total sugars. The second component was highly correlated with the content of fatty oil, total nitrogen, and protein. The third component was defined by the content of cellulose, while the fourth component was the content of starch and Brix.

The PCA-biplot graph shows the association of traits and pea genotypes based on the largest percentage of the explained variance of the first two principal components.

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HEMIJSKO-TEHNOLOŠKI SASTAV SEMENA PROLEĆNOG GRAŠKA (*PISUM SATIVUM VAR. HORTENSE* L.)

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R e z i m e

Istraživanje je imalo za cilj utvrđivanje nutritivnog kvaliteta: sadržaja vlage pepela, ulja, ukupnog azota, proteina, ukupnih šećera, skroba, celuloze i sadržaja ukupno rastvorljivih čvrstih materija (briks) semena odabranih, (tehnološki) zrelih, genotipova jarog graška (osam linija i dve sorte). Takođe, ispitana je struktura varijabilnosti analiziranih karakteristika genotipova graška i doprinos pojedinačnih karakteristika ukupnoj varijabilnosti. Poljski ogled je postavljen tokom 2022. godine na lokalitetu Rimski Šančevi na zemljištu tipa černozem, u sistemu navodnjavanja, u Odeljenju za povrtarske i alternativne biljne vrste Instituta za ratarstvo i povrtarstvo iz Novog Sada. Posebnu vrednost u selekciji povrtarskih graškova imaće linije sa većim sadržajem proteina SK-1, SK-5 i SK-10 kao i linije sa većim sadržajem šećera SK-4, SK-5 i SK-8, koje će biti uključene u stvaranje sorata graška proteinskog tipa a slađeg ukusa. Genotipovi graška SK-6, SK-7 i SK-8 sa većom vrednošću briksa možemo iskoristiti u ranijem izdvajanju graškova slađeg zrna pogodnih za svežu pijacu, tj. za rano prolećnu potrošnju. Na osnovu klaster analize, genotipovi graška su klasifikovani u četiri pojedinačne grupe na osnovu varijabilnosti ispitivanih osobina. Analizom glavne komponente, četiri odvojene komponente kumulativno su objasnile 91,91% ukupne varijabilnosti.

Ključne reči: prolećni grašak, seme, analiza glavnih komponenti, klaster.

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NUTRITIONAL AND ANTI-NUTRITIONAL COMPONENTS OF SOME UNCONVENTIONAL FEEDS

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Abstract: Animal feeding in the arid and semi-arid regions during the dry season is largely dependent on cereal crop by-products and herbaceous plants, which provide poor feed and have low nutritive value. Research is directed towards the possibility of using on-farm produced feeds as feed supplements to meet some nutrient requirements of ruminants. Nutritive and anti-nutrient contents in leaves of some tree species (*Melia azesarach, Pinus halepansis*, *Eucaliptus camaldulensis, Acacia ampliceps*, *Elaeagnus angustifolia, Casuarina equisetifolia, Sesbania aculeate, Schinus molle, Olea europea*) and agricultural by-products were determined. The crude protein values ranged from 43 to 234 g/kg DM, with the leaves of *E. angustifolia* having the highest value and sunflower seed shells having the lowest value. Crushed date palm kernels had high ($P < 0.05$) contents (g/kg DM) of total carbohydrates (878), cellulose (441) and hemicellulose (280) and low contents of lignin (25), and could therefore be used as an energy-rich feed supplement for ruminants. The highest values (41–84 g/kg DM) of tannins were noted in the tree leaves of *C. equistifolia*, *A. ambiceps*, *E. camaldulensis*, *S. molle*, *S. aculeate* and *P. halepansis*. Nitrogen solubility in the leaves of the studied tree species was negatively correlated with total phenols and tannins. The leaves of the studied tree species (with the exception of *P. halepansis*), olive cake pulp, olive tree pruning branches and leaves of olive oil extraction are suitable as protein feed supplements for ruminants in arid and semi-arid regions.

Key words: carbohydrate, fiber, nutrient, residue, tannin, tree leaves.

Introduction

The dry season in the arid and semi-arid areas is the most challenging limitation, characterized by insufficient and poor-quality feed (Babayemi, 2007). The ruminants in these areas depend mainly on cereal crop residues and annual herbaceous plants containing lower amounts of proteins and digestible organic

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matter and a higher proportion of lingo-cellulosic material, so that high levels of ruminant production are not always possible (Al-Masri, 2004 and 2005).

Tree leaves have been used as protein and mineral supplements to the low-quality roughages in the tropics during the dry periods (Kumara Mahipala et al., 2009; Khan and Habib, 2012; Habib et al., 2013). Leaves of shrubs and trees provide the required "bypass" protein and some addition compounds (glucose, propionate) which decrease enteric methane production, enhance propionic acid production from the feed consumed and hence the glucose supply to the animal, and therefore increase the animal productivity (Preston et al., 2021).

Both the cultivation of olive trees and the olive oil industry generate huge amounts of olive by-products, consisting mainly of pruning residues, leaves, stones, pulp, olive cake, and water waste (Molina-Alcaide and Yáňez-Ruiz, 2008). The recycling of these wastes is of great importance as their storage causes serious environmental, social and economic problems. An alternative utilization of olive leaves and olive tree by-products would be to use them as roughage feeds for ruminants and would have the potential for alleviating some of the feed shortages and nutritional deficiencies that occur during the dry season (Fayed et al., 2009).

The chemical composition of unconventional feeds intended for feeding is closely related to their feeding value. Some feeds contain anti-nutrient components (particularly tannins) which may bind to the protein, thus making the protein inaccessible to the rumen microbes (Getachew et al., 2000). However, the leaves of some tree species containing high amounts of tannins can be used as a feed additive in ruminant diets to decrease the enteric methane production (Kamalak and Ozkan, 2021).

The objectives of the present work were to evaluate leaves of some tree species (*Melia azesarach, Pinus* halepansis, *Eucaliptus camaldulensis, Acacia ampliceps*, *Elaeagnus angustifolia, Casuarina equisetifolia, Sesbania aculeate, Schinus molle,* and *Olea europea*), some agricultural by-products (leaves of olive oil extraction, olive cake, olive cake pulp, olive cake wood, crushed date palm kernels, peanut shells, and sunflower seed shells) and olive tree pruning branches in terms of their chemical composition, nitrogen solubility, cell wall constituents and anti-nutrient components. In addition, the relationship between the anti-nutrient components, the cell-wall constituents, the crude protein, the total carbohydrates and the nitrogen solubility was investigated.

Material and Methods

Tested plant materials

Nine tree species which are tolerant to the harsh environmental conditions (drought and salinity) (*M. azesarach, P. halepansis, E. camaldulensis, A. ampliceps*, *E. angustifolia, C. equisetifolia, S. aculeate, S. molle,* and *O. europea*), grown at the Der Al-Hajar research station about 30 km southeast of Damascus in the arid steppe region, were selected. The leaf samples of each species with 4 replicates (*n* = 4) (3 trees each) were collected randomly and manually at the vegetative stage (green leaves) (except for *M. azesarach*, at dormant stage; fall leaves) from different parts of the tree.

Seven agricultural by-products (leaves of olive oil extraction, olive cake, olive cake pulp, olive cake wood, crushed date palm kernels, peanut shells, and sunflower seed shells) were studied. Olive oil extraction leaves and olive cake were collected from 4 local factories (*n* = 4) (8 kg each). The samples of olive cake were screened using a 2.5-mm sieve to obtain olive cake pulp, and the remaining part was designated as olive cake wood. Crushed (< 3 mm) date palm kernels, peanut shells and sunflower seed shells were collected with 4 replicates (*n* = 4) (1 kg each).

The branches (stems with leaves) of the olive trees were hand-cut in the routine pruning season at a distance of 50 cm from the tip. The olive tree pruning branches were collected with 4 replicates (*n* = 4) (3 trees each).

All the collected materials were dried at room temperature (20–25 ^{o}C) for one week, ground to pass through a 1-mm sieve, and stored frozen at -20 ^{o}C in sealed nylon bags for later analyses.

Determination of components

Standard methods as described in AOAC (1990) were used for determination of dry matter (DM), ash, ether extract (EE) and crude protein (CP). Nitrogen (N) concentration was measured by the Kjeldahl method, and CP concentration was calculated as N% x 6.25. Organic matter (OM) was calculated as: OM = DM – ash. Cell-wall constituents (neutral-detergent fiber, NDF; acid-detergent fiber, ADF and lignin) were analyzed (Van Soest et al., 1991). Both NDF and ADF were not ash corrected. The acid-detergent residue was treated with H_2SO_4 to determine the lignin. Hemicellulose and cellulose were calculated from the differences between NDF and ADF and between ADF and lignin, respectively.

The total carbohydrate (CHO) was calculated according to Yisehak and Janssens (2013) as follows:

Total CHO (%) = 100 - (% CP + % EE + % ash + % lignin).

Buffer soluble nitrogen (BS-N), non-protein nitrogen (BS-NPN) and nitrogen solubility were determined according to Makkar and Becker (1996). Total phenols and tannins were determined by spectrophotometric methods (Makkar et al., 1993).

Statistical analyses

In this experiment, a one-way variance analysis was used to determine the mean differences in nutritive and anti-nutrient contents between the studied unconventional feeds. The data of the chemical measurements were subjected to a one-way analysis of variance (ANOVA) test, using the Statview-IV program (Abacus Concepts, Berkeley, CA, USA). The means were separated using the Fisher's least significant difference test at the 95% confidence level. Correlation coefficients between the studied parameters were calculated.

Results and Discussion

The values of some nutritional components of the experimental unconventional feeds are illustrated in Table 1. The crude protein content ranged from 43 to 234 g/kg DM, with *E. angustifolia* leaves having the highest content.

Table 1. Nutritive components and cell wall constituents of the experimental unconventional feeds (g/kg DM).

	CP	A	EE	NDF	ADF	L
Leaves of tree species						
M. azedarach (fall)	72.2^{d}	165.3^{a}	42.9^{j}	290.2^{p}	247.2^{m}	85.8^{l}
P. halepansis (fall)	41.7^{n}	95.3^{d}	80.0^{f}	485.4^{g}	454.7^{g}	217.0^{d}
P. halepansis (green)	66.4^{j}	63.1^{g}	72.6^{g}	479.3^{g}	373.5^{i}	134.1^{h}
E. camaldulensis (green)	78.3^{g}	109.5^{c}	78.8^{f}	322.4^{j}	256.2^{lm}	104.8^{p}
A. ambiceps (green)	126.7^{d}	118.8^{b}	19.0^{n}	389.3^{h}	297.0^{j}	118.1^{j}
E. angustifolia (green)	233.5^{a}	78.1^{f}	52.7^{i}	252.3^{l}	180.2^{no}	48.9^{n}
C. equistifolia (green)	124.7^{d}	60.8^{g}	31.1^{l}	519.0^{f}	398.4^{h}	151.6^{g}
S. aculeata (green)	164.0^{b}	113.2^{c}	56.8^{h}	244.9^{l}	172.3^{o}	65.8^{m}
S. molle (green)	136.2^{c}	85.0^{e}	144.3^{a}	293.9^{p}	187.7^{n}	63.6^{m}
O. europea (green)	92.2^{e}	65.2^{g}	33.8^{p}	365.5^{i}	257.6^{l}	126.1^{i}
Agricultural by-products						
Leaves of olive oil extraction	84.2^{f}	90.5^{d}	72.4^{g}	386.7^{h}	281.4^{p}	170.5^{f}
Olive cake	65.7^{j}	40.3^{i}	93.3^{d}	767.2^{c}	605.5^{d}	359.6^{b}
Olive cake pulp	69.5^{i}	42.8^{i}	116.4^{b}	719.0^{e}	579.3^{e}	298.9^{c}
Olive cake wood	59.3^{p}	34.6^{j}	87.1^{e}	803.0^{b}	654.5^{c}	545.1^{a}
Crushed date palm kernels	50.6^{l}	12.4^{l}	104.2^{c}	745.5^{d}	465.6^{f}	24.8^{o}
Peanut shells	51.2^{l}	27.3^{p}	15.8^{o}	880.1^{a}	799.3^{a}	366.0^{b}
Sunflower seed shells	45.4^{m}	29.6^{jp}	42.6^{j}	819.3^{b}	665.3^{b}	203.1^{e}
Tree pruning residues						
Branches of olive trees	77.6^{g}	51.8^{h}	26.9^{m}	514.8^{f}	372.7^{i}	129.4^{hi}
SEM	5.69	4.56	4.11	25.1	21.89	15.61
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

DM: dry matter; CP: crude protein; EE: ether extract; A: ash; NDF: neutral-detergent fiber; a,b,c,d…The means in the same column for each parameter with different superscripts are different at P<0.05.

The leaves of *M. azedarach* and *S. molle* had high ($P < 0.05$) concentrations of ash (165 g/kg DM) and ether extract (144 g/kg DM), respectively. The highest ($P < 0.05$) content of NDF was observed in peanut shells, sunflower seed shells and olive cake wood. Olive cake pulp had higher ($P < 0.05$) concentrations of crude protein and ether extract and lower concentrations of NDF, ADF and lignin than olive cake.

The changes in nitrogen forms, nitrogen solubility and anti-nutritional components of the experimental unconventional feeds are illustrated in Table 2. Total nitrogen, BS-N, BS-NBN and N-solubility values were varied between the experimental materials. The highest concentrations of BS-N were observed in the leaves of *M. azedarach*, *E. angustifolia* and *S. aculeate.* N-solubility was highest ($P < 0.05$) in the leaves of *M. azedarach* and *E. angustifolia* compared to the other experimental materials. There were significant variations between the experimental materials in terms of anti-nutritional components.

Table 2. Nitrogen forms, nitrogen solubility and anti-nutritional components of the experimental unconventional feeds (g/kg DM).

	Total N	BS-N	BS-NPN	N-solubility (%)	% NPN	Total phenols	Total tannins
Leaves of tree species							
M. azedarach (fall)	11.5^{d}	6.15^{b}	5.89^{b}	53.3^{a}	51.1^{a}	41.7^{j}	15.6^{hi}
P. halepansis (fall)	6.67^{n}	1.72^{g}	1.44^{j}	25.8^{d}	21.6^{d}	43.2^{j}	23.4^{g}
P. halepansis (green)	10.6^{j}	1.73^{g}	1.45^{j}	16.4^{g}	13.7^{g}	90.0^{f}	49.3^{e}
E. camaldulensis (green)	12.5^{g}	1.15^{p}	1.10^{l}	9.17^{j}	8.8^{j}	104.8^{d}	75.1^{c}
A. ambiceps (green)	20.3^{d}	1.60^{h}	1.56^{i}	7.90^{p}	7.7^{p}	122.4^{a}	58.0^{d}
E. angustifolia (green)	37.4^{a}	16.6^{a}	4.57^{d}	44.4^{b}	12.3^{h}	38.5^{p}	15.6^{hi}
C. equistifolia (green)	19.9^{d}	3.30^{d}	3.24^{e}	16.5^{g}	16.3^{f}	106.6^{c}	83.7^{a}
S. aculeata (green)	26.2^{b}	5.24^{c}	4.88^{c}	20.0^{f}	18.6^{e}	112.6^{b}	81.0^{b}
S. molle (green)	21.8^{c}	2.26^{e}	2.23^{f}	10.4^{i}	10.2^{i}	96.5e	41.2^{f}
O. europea (green)	14.8^{e}	1.36^{i}	0.89^{m}	9.23^{j}	6.0^{l}	75.4^{g}	15.9^{hi}
Agricultural by-products							
Leaves of olive oil extraction	13.5^{f}	1.74^{g}	0.84^{n}	12.9^{h}	6.3^{l}	55.1^{i}	14.9^{i}
Olive cake	10.5^{j}	0.70^{l}	0.54^{o}	6.66^{l}	5.1^{m}	6.8^{no}	0.67^{l}
Olive cake pulp	11.1^{i}	0.59^{m}	0.49^{p}	5.32^{m}	4.4^{n}	8.0^{n}	0.22^{l}
Olive cake wood	9.49^{p}	0.44^{p}	0.30^{q}	4.58^{n}	3.2^{o}	6.4^{o}	0.78^{l}
Crushed date palm kernels	8.10^{l}	1.27^{j}	1.27^{p}	16.9^{g}	15.8^{f}	30.2^{l}	12.8^{j}
Peanut shells	8.19^{l}	1.90^{f}	1.85^{g}	23.2^{e}	22.7^{c}	10.4^{m}	5.5^{p}
Sunflower seed shells	7.26^{m}	1.93^{f}	1.69^{h}	26.6^{c}	23.4^{b}	4.7^{p}	0.27^{l}
Tree pruning residues							
Branches of olive trees	12.4^{g}	1.12^{p}	10.73^{a}	9.05^{j}	5.9^{l}	57.1^{h}	17.0^{h}
SEM	0.91	0.43	0.43	1.53	1.31	4.76	3.33
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

BS-N: buffer soluble nitrogen; BS-NPN: buffer soluble non-protein nitrogen SEM: standard error of the means [a,b,c,d...] The means in the same column for each parameter with different superscripts are different at $P<0.05$.

Total phenols were highest in the leaves of *A. ambiceps* ($P < 0.05$) and lowest in sunflower seed shells, peanut shells and olive cake. The changes in the cellulose, hemicelluloses, organic matter and total carbohydrate of the experimental unconventional feeds are shown in Table 3. Total carbohydrate concentrations were highest ($P < 0.05$) in crushed date palm kernels, olive tree pruning branches and olive leaves (757–878 g/kg DM) and lowest in olive cake wood (340 g/kg DM). Olive cake pulp had a higher level of total carbohydrate content than the olive cake.

Table 3. Changes in hemicellulose (HC), cellulose (CL), organic matter (OM) and total carbohydrate (CHO) of the experimental unconventional feeds (g/kg DM).

	HC	CL	OM	CHO
Leaves of tree species				
M. azedarach (fall)	43.0^{p}	161.4^{f}	722.6^{l}	760.1^{d}
P. halepansis (fall)	30.8^{p}	237.7^{d}	828.7^{i}	648.3^{i}
P. halepansis (green)	105.8^{fg}	239.4^{d}	852.3^{h}	756.3^{d}
E. camaldulensis (green)	66.2^{j}	151.4^{f}	799.5^{j}	728.7^{ef}
A. ambiceps (green)	92.3^{hg}	178.9^{e}	776.4^{p}	734.6^{e}
E. angustifolia (green)	72.1^{ij}	131.3^{g}	822.5^{i}	697.1^{g}
C. equistifolia (green)	120.1^{e}	246.8^{d}	861.0^{fg}	716.7^{f}
S. aculeata (green)	72.7^{ij}	106.5^{i}	779.7^{p}	720.1^{f}
S. molle (green)	106.2^{efg}	124.2^{gh}	881.6^{de}	673.0^{h}
O. europea (green)	107.9^{ef}	131.5^{g}	865.1^{f}	757.5^{d}
Agricultural by-products				
Leaves of olive oil extraction	105.4^{fg}	110.9^{hi}	856.4^{gh}	638.5^{i}
Olive cake	161.6^{b}	245.9^{d}	912.8^{b}	339.8^{l}
Olive cake pulp	139.7^{d}	280.4^{c}	887.1^{d}	547.9^{j}
Olive cake wood	148.5^{bcd}	109.4^{i}	903.5^{c}	339.8^{l}
Crushed date palm kernels	279.9^{a}	440.7^{b}	922.4^{a}	877.9^{a}
Peanut shells	80.8^{hi}	433.3^{b}	880.8^{de}	641.0^{i}
Sunflower seed shells	154.0^{bc}	462.3^{a}	881.6^{de}	776.7^{l}
Tree pruning residues				
Branches of olive trees	142.1^{cd}	243.3^{d}	876.8^{e}	791.2^{b}
SEM	6.56	13.47	6.11	14.32
P-value	<0.0001	<0.0001	<0.0001	<0.0001

SEM: standard error of the means. [a,b,c,d...]The means in the same column for each parameter with different superscripts are different at $P<0.05$.

The results indicated that crude protein, total carbohydrates, total phenols, buffer-soluble nitrogen and tannins were negatively correlated with cell wall constituents (NDF, ADF, lignin) (Table 4). Nitrogen solubility in the leaves of the experimental tree species was negatively correlated with total phenols ($r = -0.80$; $P < 0.001$) and tannins ($r = -0.54$; $P < 0.001$) (Figures 1 and 2).

Table 4. The correlation coefficients between the cell wall constituents and nutritional and anti-nutritional components of the experimental unconventional feeds.

	CP	CHO	BS-N	TP	TT
NDF	- 0.66***	- 0.37**	- 0.48***	- 0.74***	- 0.58***
ADF	- 0.66***	- 0.44**	- 0.45***	- 0.74***	- 0.56***
Lignin	- 0.47***	- 0.86***	- 0.40***	- 0.61***	- 0.48***

CP: crude protein; CHO: total carbohydrates; BS-N: buffer soluble nitrogen; TP: total phenols; TT: total tannins; NDF: neutral-detergent fiber; ADF: acid-detergent fiber. ***P*<0.01, ****P*<0.001.

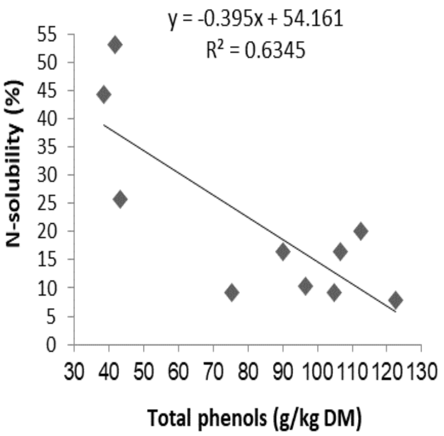

Figure 1. Relationship between N-solubility and total phenols of the leaves of experimental tree species

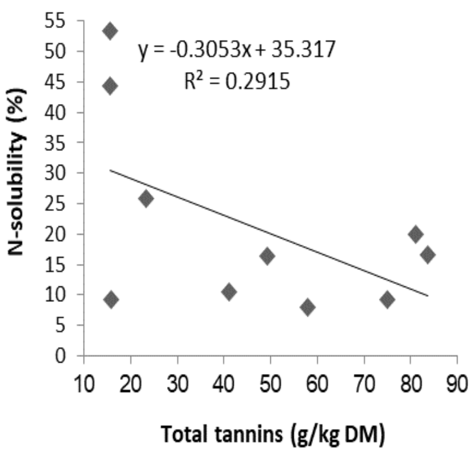

Figure 2. Relationship between N-solubility and total tannins of the leaves of experimental tree species

The crude protein concentration in the experimental leaves of *Acacia ambiceps* (127 g/kg DM) was comparable to that reported by Azim et al. (2011) for *A. nitotic* (118 g/kg DM). However, the crude protein concentrations (72 g/kg DM) in the experimental fall leaves of *Melia azesarach* were lower than those reported by the previous referent for green leaves of *M. azedarach* (141 g/kg DM). The content of crude protein of *M. azedarach* can be misleading, because up to 51% of this fraction can consist of non-protein nitrogen. Parissi et al. (2005) showed that the crude protein content of some browse species (*Medicago arborea*, *Arbutus andrachne* and *Gleditsia triacanthos*) decreased with maturation. Narvaez et al. (2010) showed that the crude protein content of 11 California browse species decreased from spring to fall. El-Waziry (2007) and Sallam et al. (2008) reported that the crude protein contents of trefoil hay and alfalfa hay, commonly used as livestock feed, were 145 and 182 g/kg DM, respectively. The minimum crude protein level of 80 g/kg DM is required for rumen microbial function (Norton, 2003). Therefore, the experimental un-conventional feeds (except for olive cake, olive cake wood, crushed date palm kernel, peanut shells, sunflower seed shells and leaves of *P. halepansis*) appear to be a good protein source for ruminants.

Lignin contents were highest in peanut shells, olive cake and olive cake wood, and lowest in crushed date palm, leaves of *E. angustifolia*, *S. aculeate* and *S. molle.* Alonso-Diaz et al. (2009) indicated that NDF concentrations in tree leaves of *Lysiloma latisiliquum*, *Acacia pennatula* and *Piscidia piscpula* were negatively correlated with dry matter digestibly. However, Jung et al. (1997) and Moore and Jung (2001) reported that the lignin concentration of forages was negatively related to the extent of digestion. This inhibition likely results from a reduction in the microbial growth rate and microbial enzyme activity in the rumen (McSweeny et al., 2001).

The rates of nitrogen solubility were highest in the leaves of *M. azedarach* and *E. angustifolia* (44–53%), intermediate in *S. aculeate* leaves, sunflower seed shells, peanut shells and the fallen leaves of *P. halepansis* (20–26%) and lowest in remnant materials (5–17%). Hussain et al. (2001) reported that BS-N rates ranged between 25 and 40% of the total nitrogen in the leaves of some *Sesbania* species. Al-Masri (2013) reported that the BS-N and BS-NPN values were negatively correlated with crude fiber and NDF concentrations (r = -0.87) of some range plants.

The concentrations of total phenols (122 g/kg DM) and total tannins (58 g/kg DM) in the experimental leaves of *A. ambiceps* were analogous or comparable to those (122 and 89 g/kg DM, respectively) reported for *Hippophae rhamnoides* by Singh et al. (2005). Pritchard et al. (1988) reported that the low intake and feed value of *Acacia aneura* leaves were related to the content of condensed tannins, which bound with the proteins in the leaves. Rubanza et al. (2005) indicated that the concentrations of condensed tannins varied between the *Acacia* species (*A. angustissima, A. drepanolobium, A. nilotica, A. polyacantha, A. tortilis, A. Senegal*) and ranged from 53 to 98 g/kg DM. Abdulrazak et al. (2000) reported that the total phenol and tannin contents in the leaves of some *Acacia* trees were negatively correlated with crude protein (r = -0.90, P < 0.01) and positively correlated with acid-detergent fiber contents (r = 0.67, P < 0.05). Getachew et al. (2002) indicated that plants containing total tannin and phenol levels up to 20 and 40 g/kg DM, respectively, do not precipitate protein and, therefore, probably do not affect ruminant productivity.

The results indicated that crushed date palm kernels had high contents of total carbohydrates, cellulose and hemicellulose and low contents of lignin. Therefore, it could be used as an energy-rich feed supplement for ruminants. Olive cake wood had high concentrations of lignin and low concentrations of total carbohydrates and therefore could not be used as a feed source. Al-Masri (2003) indicated that removing the wood from olive cake to obtain olive cake pulp improved organic matter digestibility and metabolizable energy. Our results indicated that removing the wood from olive cake to obtain olive cake pulp increased the crude protein, total carbohydrates and cellulose and decreased the cell wall constituents, and therefore olive cake pulp could be used as a feed source. Further work is required to study *in-vivo* palatability and growth performance of the experimental unconventional feeds.

Conclusion

Based on the results of this research it can be concluded that:

Crushed date palm kernels had high contents of total carbohydrates, cellulose and hemicellulose and low contents of lignin, and therefore, it could be used as an energy-rich feed supplement for ruminants.

Removing the wood from the olive cake to obtain the olive cake pulp increased the crude protein, total carbohydrates and cellulose and decreased the cell wall constituents.

Nitrogen solubility in the leaves of the studied tree species was negatively correlated with total phenols and tannins.

Leaves of the studied tree species (with the exception of *P. halepansis*), olive cake pulp, olive tree pruning branches and leaves of olive oil extraction are suitable as protein feed supplements for ruminants in arid and semi-arid regions.

In-vivo palatability and growth studies for the experimental unconventional feeds are necessary to complete the experiments and confirm the results.

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NUTRITIVNE I ANTINUTRITIVNE KOMPONENTE NEKIH NEKONVENCIONALNIH HRANIVA

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R e z i m e

Ishrana životinja u sušnim i polusušnim regionima tokom sušne sezone u velikoj meri zavisi od nusproizvoda žitarica kao i krmnog bilja, koje obezbeđuje lošu stočnu hranu, niske hranljive vrednosti. Istraživanja su usmerena ka mogućnosti korišćenja hraniva proizvedenih na gazdinstvu u vidu dodatne ishrane, kako bi bile podmirene hranidbene potrebe preživara. Utvrđen je sadržaj nutritivnih i antinutritivnih sastojaka u lišću nekih drvenastih vrsta (*Melia azesarach, Pinus halepansis*, *Eucaliptus camaldulensis, Acacia ampliceps*, *Elaeagnus angustifolia, Casuarina equisetifolia, Sesbania aculeate, Schinus molle, Olea europea*) i sporednih poljoprivrednih proizvoda. Vrednosti za sadržaj sirovih proteina kretale su se od 43 do 234 g/kg SM, pri čemu su listovi *E. angustifolia* imali najvišu vrednost, a ljuske semena suncokreta najnižu vrednost. Drobljene koštice urmine palme odlikovale su se (P < 0,05) sadržajem (g/kg SM) ukupnih ugljenih hidrata (878), celuloze (441) i hemiceluloze (280), a niskim sadržajem lignina (25), pa su se stoga mogle koristiti kao energetski bogat dodatak ishrani preživara. Najviše vrednosti (41–84 g/kg SM) tanina su zabeležene u lišću drvenastih vrsta *C. equistifolia*, *A. ambiceps*, *E. camaldulensis*, *S. molle*, *S. aculeate* i *P. halepansis*. Rastvorljivost azota iz lišća ispitivanih drvenastih vrsta bila je u negativnoj korelaciji sa ukupnim fenolima i taninima. Lišće ispitivanih drvenastih vrsta (sa izuzetkom *P. halepansis*), pulpa maslinove pogače, grančice-ostaci od orezivanja maslina, kao i lišća, nakon ekstrakcije maslinovog ulja, pogodni su kao proteinski dodaci hranivima za preživare u sušnim i polusušnim regionima.

Ključne reči: ugljeni hidrati, vlakna, hranljive materije, ostaci, tanini, lišće drveća.

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FIELD TEST, RESEARCH AND RESULTS OF A FLEXIBLE MACHINE WITH A ROTOR

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Abstract: Science-based farming systems have proven that the soil layer after plowing contains 100–200 million to 2–3 billion weed seeds per hectare, 70–90% of which can be destroyed by harrowing before and after emergence. Pre-sowing cultivation with rotor trowels leads to the development of seeds in the soil and the creation of an aeration process for the root system during the growing season, which improves plant development and productivity. A flexible trowel with a rotor was developed in our laboratory. Constructive and technological parameters were analyzed using the experimental planning method and optimal results were obtained, considering the diameter of the rotor and the speed of the unit as the main influencing factors. The "percentage of lump crushing" was the output parameter, and the "soil moisture" was the input parameter. The regression equation and diagrams were obtained from the mathematical analysis. Optimally, based on 4 experiments, the unit speed V=15 km/h, the cultivation depth 5–10 cm, and the rotor diameter D=380 mm were selected. The technological operations carried out using a flexible trowel with a rotor made 81.28% of the lump crushing in the soil, which had a significant effect of 95% on the development of the sown seeds. In the field test, the degree of "lump crushing" was studied in the soil with a moisture content of 18–24%. It was found that the fraction of soil with a size of less than 10 mm amounted to 51%.The size of the lumps was 10–25, those of 25–50 and 50–100 mm made up 18%, 13% and 14% of the soil, respectively. The size of lumps above 100 mm made up 4% of the soil.

Key words: machine, lump crushing, soil, rotor, flexible trowel.

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Introduction

In modern times, one of the most global problems of humanity is providing the population with food products, and the most important issue is paying for this provision. At present, the countries of the world, international organizations, especially the Food and Agriculture Organization of the United Nations (FAO), the World Bank, the International Fund for Agricultural Development (IFAD), the International Monetary Fund and other organizations are committed to reducing the number of people suffering from hunger, ensuring minimum food requirements, addressing other aspects of food security, etc. Extensive work is being done considering the problems. According to FAO recommendations, investments in agriculture should be increased by 50 percent.

In our country, it is important to achieve a reliable supply of food products so that the population does not face such a problem in the future. Cereal farming is of special importance in the food supply of the country's population. This is because grain farming is of great importance in meeting the population's demand for bread and bakery products, as well as in meeting the demand for strong and coarse fodder in animal husbandry (Borisenko, 2015; Maslov, 2017; Kambulov, 2008).

In recent years, the State Programs adopted in order to improve the food supply of the country's population have given a strong impetus to the development of grain farming. The goal in grain farming is to increase productivity per hectare. In order to achieve a successful solution to these issues, it is necessary to use advanced technologies and the latest achievements of science in the production of grain products in order to obtain high-quality products from a single cultivated area and increase the annual grain production to 5.0 million tons. There are real opportunities for this in our republic. The decrees signed by the President of the Republic of Azerbaijan on the development of grain farming require further attention to this field. It should be noted that 1,058,398.9 hectares of grain fields were planted in the country this year, of which 658,383.7 hectares include wheat and 400,015.2 hectares comprise barley. By keeping the cultivated area for grain growing in our republic around 1,395 thousand hectares, it is possible to increase the yield per hectare to 4.0–4.5 tons, and the annual grain production to 5 million tons. It is possible to achieve high productivity every year by implementing important technological measures in the cultivation of grain crops in a complex manner and by following agrotechnical measures correctly. The territory of the Republic of Azerbaijan, distinguished by the diversity of its natural geographical features, is characterized by the presence of all soil-climate zones spread across the globe, except for tropical and forest-savanna-type landscapes. Our republic has rich climatic resources due to favorable physical and geographical conditions. All this creates a favorable opportunity for the cultivation of many agricultural plants in Azerbaijan. Azerbaijan is an ancient agricultural land. Favorable natural-geographical conditions of the area where the country is located have created the basis for the comprehensive development of agriculture since ancient times.

The purpose of pre-sowing soil cultivation is to make the structure of the soil granular, clear the field of weeds, apply the remains of culms, organic and mineral fertilizers to the subsoil, and destroy the eggs and larvae of pests by uncovering them (Zhukova, 2010; Malyuga, 2014).

The following main tasks are performed in pre-sowing soil cultivation:

1. Preventing the loss of moisture from the soil layer, strengthening microbiological processes and creating a soft soil layer with a smooth surface;

2. Destroying weeds and preventing their germination after sowing;

3. By burying the seed to any depth, carrying out quality sowing.

Flexible rotary trowels are widely used in developed countries (Marinina et al., 2017).

Flexible rotor trowels are designed to work in early spring frost plowed areas with a lot of plant residues, even after the use of soil conditioners and mulchers, as well as on no-till and rest soils (Alekseev, 2002; Kambulov, 2018). It is used in soil-saving and energy-saving technologies in horticulture. The cultivation of the soil with rotating tines placed on the rotor is particularly important for its moisture conservation, as it allows plant residues and weeds to be removed down to the soil surface, forming a mulch layer that breaks up the soil capillaries and improves moisture retention (Demshin and Vladimirov, 2010) .

The flexible rotor trowel has the following features (Ryazanov, 2010)

- softening the soil to a depth of 2–8 cm, regular distribution of plant residues and weeds on the soil;
- crushing and scrubbing of lumps;
- creating a mulch layer on its surface to keep moisture in the soil;
- dispersing the soil crust and capillaries to reduce water evaporation in the soil;
- reducing the costs incurred for the destruction of weeds and spraying of agrochemicals, including direct sowing (no till);
- reducing the costs of fuel and lubricants to achieve high productivity;
- regulating the force acting on the soil by pressing the working bodies to the soil;
- improving soil aeration (ventilation);
- favorable cultivation of irrigated lands;
- removing weeds by their roots without being cut off (plucked out) and placed on the ground;
- the presence of a flexible shaft and a large angle of attack prevents it from becoming clogged with sticky soil and moist plant residues.

Material and Methods

The following standards were used during the testing of the flexible cable trowel:

- GOST 33687-2015 Machines and tools for surface treatment of soil (Nagiyev et al., 2023)

The average speed of the machine, km/h, was calculated by the following formula:

$$V = \sum_{i=0}^{n} \frac{L_i}{t_i}\ 3.6 \quad (1)$$

where:

L_1 is the length of the distance in the i-repetition, m;

ti – i-repetition distance crossing time, sec.;

n – number of repetitions, times.

In order to determine the distance of the herd and the time to cover that distance, they divided the total distance equally, not less than 50 m, marked the time and recorded the time with a stopwatch.

This was repeated four times (twice when the unit moved in the straight direction and twice in the opposite direction), the measurement error was 1 second. The cultivation depth (softened layer) was measured with a ruler, by putting the line to the uncultivated depth of the soil. For this purpose, the measurements were repeated no less than 25 times.The measurements were made in the direction of movement of the machine at intervals of 1 m along the track of the working body. If the footprint of the working body is predetermined, then the measurement is taken at an equal distance to the entire working width of the machine. If there is a rough surface behind the working body, the measurement is made in the dash and in the furrow. The average number was determined from two measurements (Figure 1).

Figure 1. Wooden frame for taking the measurements.

The experiment was repeated four times (twice in the direction of movement and twice in the opposite direction).

The depth measurement error can be 1 cm. The measurement numbers were entered in the table and processed by statistical methods.The accuracy of the calculation was up to 1/10. The soil compaction was determined according to the sample taken.The sample was taken from 4 points of the field (two in the direction of the movement of the aggregate, and two in the opposite direction) at the depth of cultivation in the field of 0.25 m^2.

A set of 0.50 x 0.50 m frame and metal sieves was taken to determine soil crushing.Soil samples corresponding to the fractions passed through the sieves with the diameter of the sieve holes (10, 25, 50 and 100 mm) were taken. A digital scale was used. When analyzing the samples, large buckets were first selected, and then the soil was poured into buckets with a diameter corresponding to the gradation mentioned above.

A set of sieves was placed in decreasing order of the diameter of the holes on them.The soil fraction less than 10 mm was poured into the bottom of the set of sieves. By carefully shaking the sieves, it was ensured that the soil was poured in fractions. The mass of each lump was determined with an error of 50–100 g.The ratio of the mass norm of the lump and the mass share of the lump to the total mass was calculated (Figure 2).

The calculation was done with an accuracy of one lump of a percent. The mass measurement value of each lump was determined by dying 4 times, and its average mathematical value.

The crushing of lump clods in the field depends on the structural parameters of the flexible rotor trowel, the structural parameters of the soil and the speed of the unit. Since the study and testing of a flexible rotor trowel for soil tillage required several application periods and the process itself was limited by agrotechnical conditions, it was appropriate to combine field research and testing with process simulation.For the optimization of the factors in the implementation of the technological process, the crushing percentage of the pulp was taken as the output parameter, and the moisture of the soil was taken as the input parameter. It is related to the following factors that have a greater effect on the output parameters (Gurbanov et al., 2015).

Controlling factors were as follows:

X1 (D) – rotor diameter;

X2 (V) – machine speed.

Figure 2. A set of sieves for determining the fractional composition of the soil.

We can use a 4-centered, orthogonal, first-order composite planar to construct a mathematical model in which the output parameters vary in three levels, for each of which a base level and a change step have been set.

The factors themselves were coded according to the expression:

$$X_i = \frac{K_i - K_{oi}}{E} \qquad (2)$$

where:

X_i is the encoding of the value of the factor;

K_i is the true value of the factor;

K_{oi} is the true value of the factor at the zero level;

E – change interval.

In the next step, we moved on to coded variables, X_1 and X_2:

$$X_1^{min} = \frac{p^{min} - p^0}{\Delta p} = -1; \quad X_1^{max} = \frac{p^{max} - p^0}{\Delta p} = +1 \qquad (3)$$

$$X_2^{min} = \frac{w^{min} - w^0}{\Delta p} = -1\,; \quad X_2^{max} = \frac{w^{max} - w^0}{\Delta w} = +1 \qquad ....(4)$$

where:
p – rotor diameter variable values ;
w – variable speed of the agregate.

To determine the dependence, we drew up a matrix for planning experiments:

$$y = f\,(x_1, x_2); \quad ....(5)$$

For simplicity, we denoted here:

$$y = \frac{p}{p_0}; \quad ....(6)$$

The first experiment was carried out (table in the first line) when p = m, correspondingly w = m_1 and the second experiment, when p = n, correspondingly w = m_1 and so on. The "output" column shows the average (taking into account the repetition of the experiments): p/p_0.

The matrix (in Table 1) was thus constructed in such a way that each variable X_j only took on two values in the experiments (+ or -), that is, it only changed at two levels (at the upper and lower limits).

Table 1. Planning the experiment.

Variant number	To be planned			The result	Output parameters
	X_0	X_1	X_2	X_1X_2	Y
1	+1	-1	-1	+1	80,6
2	+1	+1	-1	-1	83,3
3	+1	-1	+1	-1	81,4
4	+1	+1	+1	+1	81,3

X_1(D) is the diameter of the rotor in the rotor trowel, X_2 (V) is the speed of the rotor trowel, Y is the percentage of crushing.

In this case, all possible combinations of X_j variables were involved in a full factorial experiment (TFT).

The coefficients were calculated and the adequacy of the response equation was analyzed.

The Bj coefficients were calculated according to formula (5).

It follows from the orthogonality property of the plan that if we take any two columns in the completed matrix and multiply the indices in the same rows in pairs, then all the columns obtained in this way – in the results 2^{k2} of all four numbers in the plan or 2^{k3} in eight numbers – are equal to zero.

This feature was sometimes used to plot missing columns, for example, when studying the interaction of factors (Table 2).

It should be noted that for large values, TFT involves more experience than is necessary to calculate the coefficients of the linear equations (without taking into account interactions) (Mammadov and Ibrahimov, 2007):

if k = n factors, then $N = i^n$ experiments.

Table 2. Controllable factors and their change interval.

Input parameter	Level of coded variables	Factors	
		The speed of the unit, km/h X_1	Rotor diameter, mm X_2
Soil moisture	Down (+)	10	360
	Basis (+)	15	380
	Up (+)	20	400
	Variation interval, ε	5	20

Depending on the selected factors, a regression equation was obtained for the splitting of the top layer of the soil by the rotating working body and the crushing of the lumps:

$$y=81,28+0,52X_1-0,17X_2-0,53X_1X_2 \quad (7)$$

where: y – crushing of the soil with the rotor teeth.

Figure 3. The general view of a flexible trowel with a rotor.

Figure 4. Testing of a flexible rotor trowel.

Results and Discussion

An overview of the proposed flexible trowel with a rotor is given in Figures 3 and 4. At that time, the working speed of the unit was 14–16 km/h, the width was 3.5 m, and the cultivation depth was 5–10 cm.

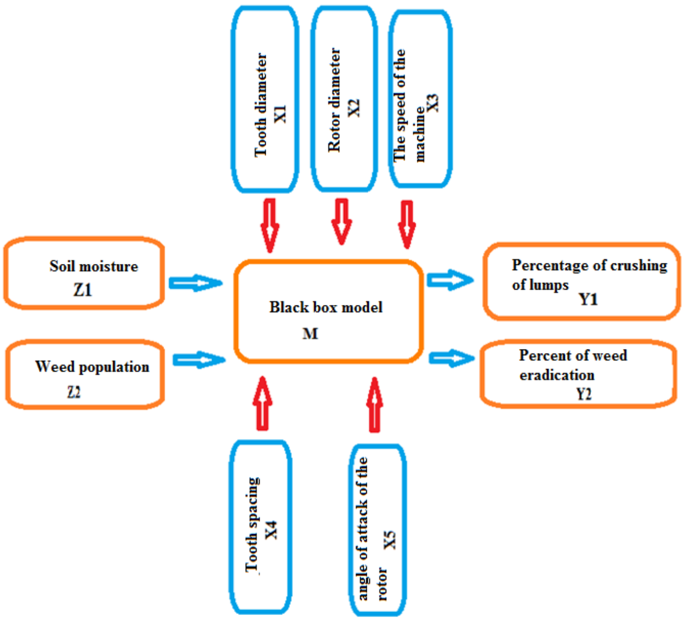

Figure 5. The mathematical model of the influencing factors of a flexible rotor trowel.

Depending on the diameter of the rotor, the effect of the speed characterizes the lump crushing phases, with the outside numbers indicating the speed of the unit, and the numbers written outwards from the center indicating the diameter of the rotor (Figure 7).

A mathematical structural model of a flexible trowel with a rotor was built, in which the influencing factors, input and output parameters, are shown (Figure 5).

From the 3-dimensional graph obtained from the regression equation, it is clear that with a diameter of the rotor of 380 mm and a speed of the unit of 15 km/h, the maximum crushing was 81.28%. The peak limit was considered optimal (Figure 6). Two main factors affecting crushing were analyzed and graphed using the Excel software according to the mathematical theory.

Soil moisture was determined during the test. It was found that the moisture in the 0–5, 5–10 and 10–15-cm layers of the soil was 18%, 21% and 24%. The average density of the soil was 0.986 g/cm^3. After the machine went through the test, the percentage of crushing of the lumps was studied. It was found that the soil fraction less than 10 mm accounted for 51% (Table 3).

The size of the lump fractions of 10–25, 25–50 and 50–100 mm constituted 18%, 13% and 14%, respectively. The size of lumps above 100 mm accounted for 4% of the soil.

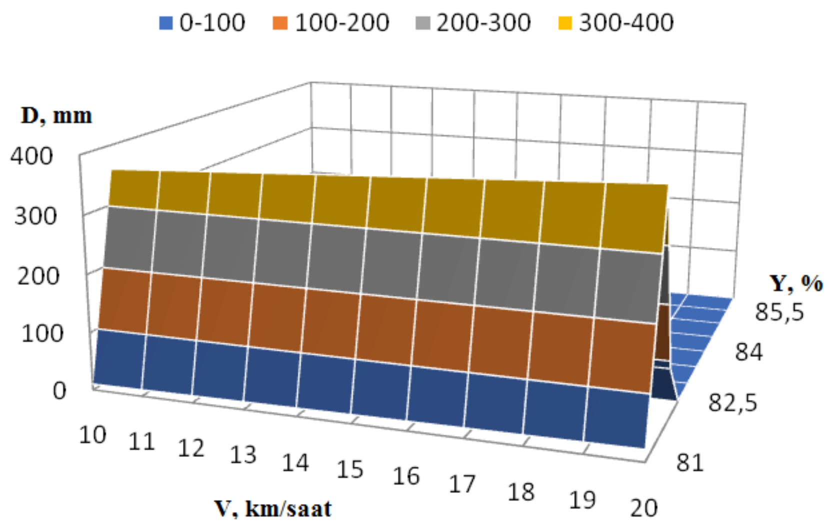

Figure 6. The dependence of the soil crushing percentage on the influencing factors.

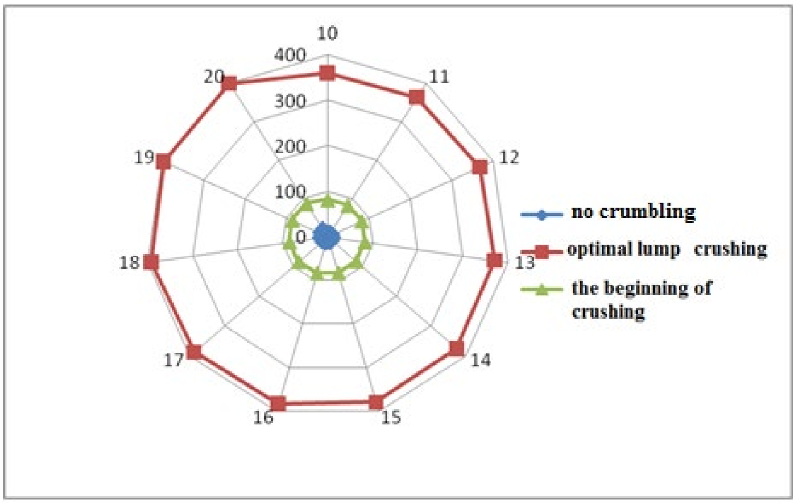

Figure 7. Phases of soil crushing depending on the diameter of the rotor.

Table 3. Determining the soil crushing quality.

Repetition	Lump sizes , mm						Total sample weight	
	10 down	10–25	25–50	50–100	100 up	10 down		
	kq	%	kq	%	kq	kq	kq	%
1	4.8	49.2	1.8	18.4	1.25	4.8	9.75	100
2	4.9	51.1	1.7	17.8	1.3	4.9	9.50	100
3	5	52.01	1.6	16.6	1.2	5	9.60	100
4	4.7	48.9	1.9	19.7	1.2	4.7	9.60	100
Total	19.4	201.6	7	72.5	4.95	19.4	38.45	400
Middle	4.85	51	1.75	18	1.23	4.85	9.6	100

Conclusion

During the experimental test, the working speed of the machine was 14–16 km/h, the width was 3.5 m, and the cultivation depth was 5–10 cm.

According to the agrotechnical conditions, the degree of crushing of the lumps was 81.28% on average.The diameter of the rotor trowel was D=380 mm, and the technological operation speed was optimally chosen as V=15 km/h.

The size of the lump fractions of 10–25; 25–50 and 50–100 mm constituted 18%, 13% and 14%, respectively.The size of lumps above 100 mm accounted for 4% of the soil.

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TERENSKO ISPITIVANJE, ISTRAŽIVANJE I REZULTATI ISPITIVANJA KOMBINOVANE MAŠINE SA ROTOROM

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R e z i m e

Naučno zasnovani poljoprivredni sistemi su dokazali da sloj zemljišta nakon oranja sadrži od 100–200 miliona do 2–3 milijarde semena korova po hektaru, od kojih se 70–90% može uništiti drljanjem pre i posle nicanja. Predsetvena obrada rotacionom drljačom sa motičicama dovodi do razvoja semena u zemljištu i stvaranja aeracije za korenov sistem tokom vegetacione sezone, što poboljšava razvoj i produktivnost biljaka. U našoj laboratoriji razvijena je kombinovana drljača sa motičicima. Konstruktivni i tehnološki parametri su analizirani metodom planiranja eksperimenta i postignuti su optimalni rezultati, uzimajući u obzir prečnik rotora i brzinu jedinice kao glavne faktore uticaja. „Procenat sitnjenja grudvi" bio je izlazni parametar, dok je „vlažnost zemljišta" bio ulazni parametar. Regresiona jednačina i dijagrami su dobijeni matematičkom analizom. Optimalno, na osnovu 4 ponavljanja, odabrana je brzina jedinice V=15 km/h, dubina obrade 5–10 cm i prečnik rotora D=380 mm. Tehnološke operacije sprovedene korišćenjem kombinovane drljače sa motičicima sa rotorom postigle su 81,28% sitnjenja grudvi u zemljištu, što je imalo značajan uticaj od 95% na razvoj posejanog semena. U poljskom ispitivanju, proučavan je stepen „sitnjenja grudvi" u zemljištu sa sadržajem vlage od 18% do 24%. Utvrđeno je da je frakcija zemljišta veličine manje od 10 mm iznosila 51%. Grudve veličine 10–25 mm, 25–50 mm i 50–100 mm činile su 18%, 13% odnosno 14% zemljišta. Grudve veće od 100 mm činile su 4% zemljišta.

Ključne reči: mašina, sitnjenje grudvi, zemljište, rotor, kombinovana drljača sa motičicama.

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UNLEASHING THE EFFICIENCY AND POTENTIAL OF INDONESIAN FISHERY EXPORTS TO THE EUROPEAN UNION MARKET

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Abstract: The free trade agreement (FTA) between Indonesia and the EU is anticipated to boost Indonesia's economic growth, particularly in trade. However, from 2020 to 2022, EU countries issued 38 notifications concerning Indonesian exports, primarily related to sanitary and phytosanitary measures, which are non-tariff barriers in free trade. Indonesia has not benefited from the positive trend in EU fishery commodity imports. This study addresses the research gap on the efficiency and export potential of Indonesian fishery products in the EU market. It aims to assess factors influencing trade flow, export efficiency, and export potential of Indonesian fisheries to the EU using the stochastic frontier gravity model (SFGM). The SFGM in the gravity model determines the maximum potential trade level achievable in bilateral trade. This research utilized panel data on Indonesian fishery exports to the EU-27 countries from 2003 to 2021 (19 years). This study analyzed the HS 03 products—fish, crustaceans, mollusks, and other aquatic invertebrates—exported from Indonesia to 25 EU countries. The results indicated that the GDP of both exporting and importing countries, competitiveness and the exchange rate of the rupiah against the US dollar positively impacted fishery exports to the EU. Conversely, distance, represented by trade costs, negatively impacted Indonesia's fishery exports in the EU. The findings showed Indonesia did not have a 100% efficiency value. The highest market potential for Indonesia in the EU was in exporting fishery products to France, Italy, Germany, Austria, and Spain.

Key words: export, European Union, fisheries, Indonesia, trade efficiency, trade potential.

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Introduction

The openness of the global market has encouraged every country to increase its participation in the global market. A country's participation is determined by its competitiveness (Abukari and Cunfeng, 2021; Sa'diyah and Darwanto, 2020) and the relations between countries (Guan and Ip Ping Sheong, 2020) which have a positive influence on the trade balance. Global market openness is followed by the increased implementation of free trade agreements (FTAs). The FTA is a collaboration consisting of 3 main components, namely trade in goods, trade in services and investment. The FTA is structured to reduce the application of trade tariffs, quotas and trade barriers to a group of products, or to all products traded. The application of this FTA is expected to be an effort to increase trade among countries, which is the result of easing and reforming of the bureaucracy that can remove institutional and economic barriers (Kepaptsoglou et al., 2010). Over the past 25 years, Indonesia has implemented FTAs in the international market in the form of multilateral, regional and bilateral agreements (Purwono et al., 2022). By 2021, Indonesia had had 40 FTAs (CSIS Indonesia, 2021). The application of FTA in Indonesia is expected to strengthen relations among countries, which can increase the flow of Indonesian trade to FTA partner countries.

One of Indonesia's main trading partners in the international market is the European Union (EU). Indonesia's trade balance with the EU has a surplus value although it fluctuates every year (CSIS Indonesia, 2021). Indonesia's export growth rate to the EU reached 33.53 percent in 2021. The value of Indonesia's exports with the EU reaches US$ 19,243,110,000, with agricultural commodities accounting for the largest proportion of 33.85 percent. Even though the growth rate of Indonesia's export to EU countries is relatively high, Indonesia's market niche in the EU market is still relatively low compared to other major exporting countries. The Indonesian market niche in the EU market was only 1.03 percent in 2021 (Trade Map, 2023). When compared to other ASEAN countries, Indonesia is still lagging behind in controlling the EU market niche. Although the Indonesian market niche has a positive trend, the increase has not been significant and is still lower compared to Singapore, Vietnam, Malaysia, and Thailand (Figure 1).

The implementation of the FTA between Indonesia and the EU is expected to be a catalyst for Indonesia's economic growth, particularly in the trade sector. Theoretically, FTAs increase trade flows between the two partners (Ingot and Hastjarjo, 2017). Therefore, Indonesia wants to work with the EU to enhance economic diplomacy through the Indonesian-European Union Comprehensive Economic Partnership Agreement (IEU-CEPA). The IUE-CEPA will hopefully reduce various existing trade barriers, so that Indonesian products will become competitive and diversified (CSIS Indonesia, 2021). For the 2020–2022 period, there were 38 notifications assigned by EU countries for Indonesian export products (RASFF, 2023). The majority of the notifications were related to sanitary and phytosanitary measures, which are a non-tariff measure in free trade. As much as 24 percent of notifications were imposed on Indonesian fishery products exported to the EU market (RASFF, 2023). This causes Indonesia to lose trade potential that can be realized in the EU market.

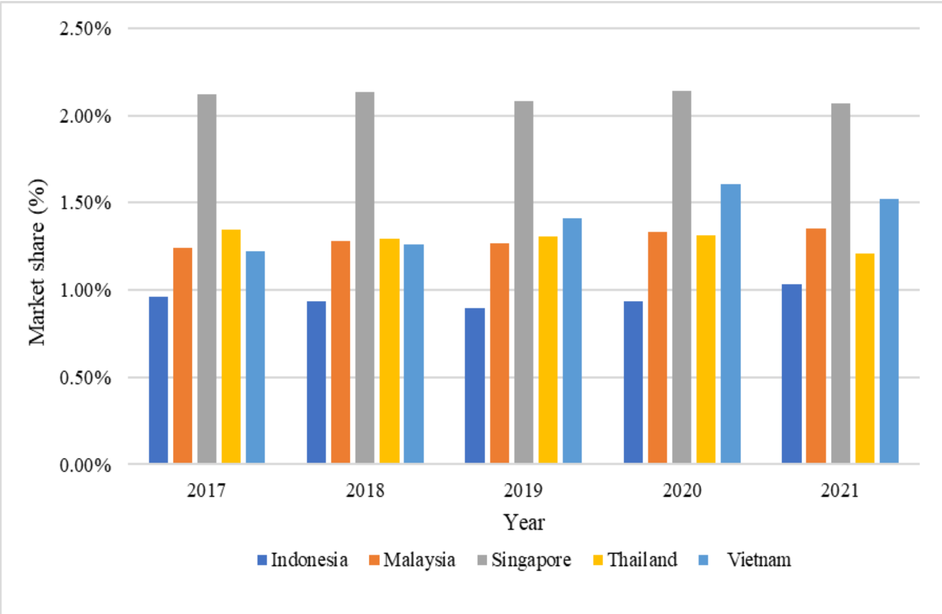

Figure 1. The market share of ASEAN members in the EU market.

On the other hand, the import value of fishery products in the EU reached US$ 48,442,785,000 in 2021 (Figure 2). Imports of EU fishery products have a positive trend with a growth rate reaching 17.68 percent in 2020–2021 (Trade Map, 2023). This condition illustrates that the potential for developing the fishery sector in the EU is still open. In terms of production, Indonesia has a comparative advantage in the utilization of fishery resources. Indonesia is one of the top 15 countries with the largest number of fish catches in the world (Laksani, 2019) with a maximum sustainable yield potential of around 6.4 million tonnes per year (Rasyid, 2015). However, the positive trend in EU fishery commodity imports has not been fully utilized by Indonesia, with fishery production also having a positive trend.

Several studies have been conducted to analyze the competitiveness of Indonesian fishery products in the international market using the revealed comparative advantage (RCA) and constant market share (CMS) methods in the international market (Aisya et al., 2017), the ASEAN-China market using the RCA method (Saptanto, 2011), and in the ASEAN-Canada market using the RCA, Export Product Dynamic and X-Model Product Export Potential methods (Luhur et al., 2019). Other research analyzed the export opportunities of fishery products in the EFTA market using a descriptive statistical approach and a trade potential indicator (Salam and Lingga, 2017) and a strategy to increase exports of fishery and marine products in the EU market using a SWOT analysis approach (Ali Mursit et al., 2022).

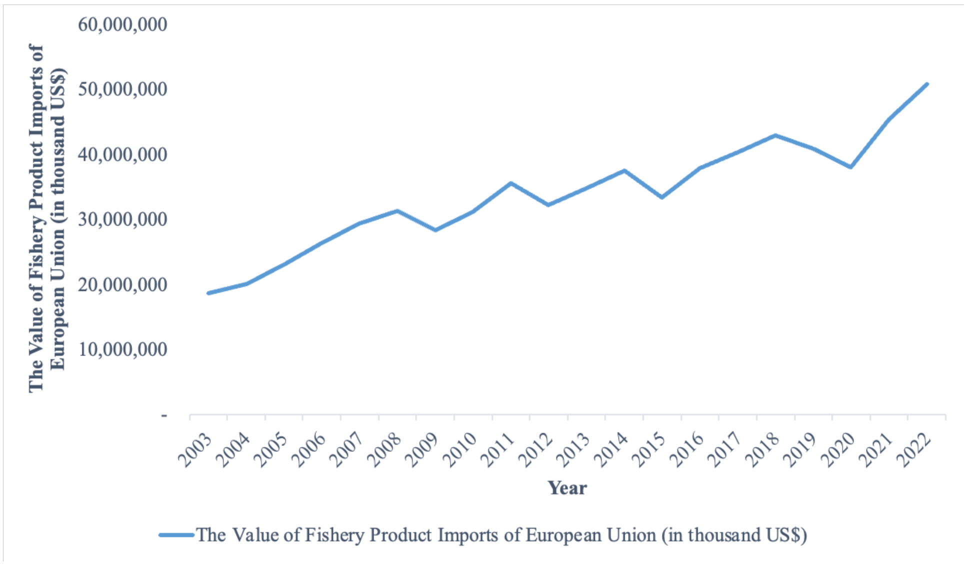

Figure 2. The value of fishery product imports of the European Union (in thousand US$).

In addition, other studies examine the factors affecting trade in the Indonesian fishery sector in international markets using a gravity model approach (Saragih et al., 2022; Hidayati et al., 2015; Saptanto and Soetjitpto, 2017) as well as research analyzing trade barriers in the form of tariff (Adam, 2018; Laksani, 2019) and non-tariff (Handoyo, 2019; Laksani, 2019) policies. The research conducted so far has not yet reached the stage of analyzing the efficiency of exports of Indonesian fishery products to the EU market as Indonesia's main trading partner in the international market. Export efficiency shows the level of resistance of a trade flow (Ravishankar and Stack, 2014) and the capability of a country to benefit from regional market integration (Tamini et al., 2018). Therefore, this study was designed to fill the current research gap relating to the efficiency and export potential of Indonesian fishery products in the EU market. The purpose of this study was to analyze the factors influencing the flow of Indonesian fishery trade, export efficiency and the export potential of Indonesian fishery in the EU market by using the stochastic frontier gravity model approach.

Material and Methods

Empirical model/Gravity model

This study used a specific gravity model to estimate the factors influencing exports of fishery products to the EU market. The standard form of the gravity equation is calculated as follow (Anderson and Van Wincoop, 2003; Balogh and Leitão, 2019; Bergstrand, 1989; Blanes, 2005):

$$EXPORT_{ij,t} = \beta_0 \times \frac{GDP_{i,t}^{\beta_1} \times GDP_{j,t}^{\beta_2}}{DIS_{ij,t}^{\beta_3}} \times \varepsilon_{ij} \qquad \text{(Eq.1)}$$

$EXPORT_{ij,t}$ is the value of Indonesian fishery product export to importing country j at time t; $GDP_{i,t}$ and $GDP_{j,t}$ are proxies for the size of the economy of the country conducting bilateral trade at time t; $DIS_{ij,t}$ is a variable describing the distance between two countries conducting bilateral trade and the error term is ε_{ij}^{t} (Ravishankar and Stack, 2014). The gravity model is the most frequently used model in research related to international trade to estimate the factors influencing bilateral trade (Boughanmi et al., 2021). The parameters of the majority gravity model were estimated using data from a group of countries reflecting normal trade relations. However, this model had a weakness because the potential for increased trade between countries was only expressed by the average sample used, but not by the maximum amount that each country could achieve in the market. Transforming Equation 1 into a linear form for Indonesian fishery product exports can be achieved by taking the natural logarithm, as demonstrated by the following expression:

$$ln\ EXPORT_{ij}^{t} = \beta_0 + \beta_1 ln\ GDP_{i}^{t} + \beta_2 ln\ GDP_{j}^{t} - \beta_3 ln\ DIS_{ij} + \varepsilon_{ij} \qquad \text{(Eq. 2)}$$

When measuring trading potential using the average value of samples in a model, it is difficult to achieve optimal values because the predicted value of the gravity model continues to decrease when trade data far from the average value is included in the model (Abdullahi et al., 2021a; Abdullahi et al., 2022). An alternative to overcome this problem (Belotti et al., 2013; Kalirajan, 2007; Kumbhakar et al., 2015) is to introduce the stochastic frontier analysis (SFA) approach to explain the trade potential in the gravity model. The SFA approach used in the gravity model is the maximum potential level of trade that can be achieved through bilateral trade. This approach compares the magnitude of trade in the sample countries with the predicted frontier values of the trading partners, so that the maximum potential trade capacity between these countries is determined (Atif et al., 2017a).

Stochastic frontier gravity model (SFGM)

The development of the gravity model estimated using SFA was developed through research (Aigner et al., 1977; Meeusen and Broeck, 1977), which estimated the technical efficiency of the production function. SFA can provide an overview of the maximum output obtained from a number of optimal inputs (Abdullahi et al., 2021a). Unlike the SFA in the production function, the stochastic frontier gravity model (SFGM) has a different basic form, which is typically that of the traditional SFGM:

$$T_{ijt} = \alpha + \beta_i X_{ijt} + v_{ijt} - u_{ijt} \quad \text{(Eq.3)}$$

Within the stochastic frontier gravity model, T_{ijt} is the actual trade volume, T^*_{ijt} is trade potential. Trade potential represents the optimal trade scale from country i to country j in t period and TE_{ijt} is the technical efficiency of country i to country in year t and can be written as follows (Jiang et al., 2022a):

$$T_{ijt} = f(X_{ijt}, \alpha) exp(v_{ijt}) exp(-u_{ijt}) u_{ijt} \geq 0 \quad \text{(Eq.4)}$$

$$lnT_{ijt} = \ln f\,(X_{ijt}, \alpha) + v_{ijt} - u_{ijt}, u_{ijt} \geq 0 \quad \text{(Eq.5)}$$

$$T^*_{ijt} = f(X_{ijt}, \alpha) exp(V_{ijt}) \quad \text{(Eq.6)}$$

$$TE_{ijt} = {T_{ijt}}/{T_{ijt}{*}} = exp\,(-u_{ijt}) \quad \text{(Eq.7)}$$

In this case, x_{ijt} represents the variables determined to have an influence on the actual trade. This is in accordance with the theory of gravity, namely GDP, distance, and others. Further, α represents an unidentified parameter vector. Then,

v_{ijt} represents deviations in the estimates caused by factors that cannot be controlled, for example, statistical errors and meet the normality criteria. Moreover, u_{ijt} shows the non-efficiency of trading. This measures the factors influencing trade resistance not included in the model built, such as government policies, tariff levels and others (Abdullahi et al., 2021b). When the value of $u_{ijt} > 0$, the bilateral trade that occurs can be categorized as having a non-efficient effect on trade, and the value of $TE_{ijt} \in (0,1)$ describes the level of actual trading, which is smaller when compared to the potential trading volume. If the value of $u_{ijt} = 0$, there is no trade non-efficiency bilateral trade and if $TE_{ijt} = 1$, the actual level of trade is equal to the sum of the potential trade volume of each country (Jiang et al., 2022b).

This study used SFGM with time variation. In this model, a transformation from the conventional gravity model (Equation 2) to SFGM with varying time was carried out in order to estimate the trade of Indonesian fishery products in the EU market. The equation was arranged as follows:

$$ln\,EXPORT_{ij}^{t} = \beta_0 + \beta_1 ln\,GDP_i^t + \beta_2 ln\,GDP_j^t - \beta_3 ln\,DIS_{ij} + \beta_4 RSCA_{ij}^t + \beta_5 EXRATEINDO_{ij}^t + \beta_6 CPI_j^t + v_{ij}^t - u_{ij}^t \quad \text{(Eq.8)}$$

Equation 9 is almost the same as Equation 2 in this study, but Equation 9 divides the error term ε_{ij}^{t} into two segments. In this case, V_{ij}^{t} indicates statistical interference in measuring errors and factor inefficiencies, while U_{ij}^{t} indicates measurements of trading performance. $\boldsymbol{EXPORT_{ij}^{t}}$ is the Indonesian fishery product export to importer country at time t; GDP_i^t and GDP_j^t are the gross domestic product of Indonesia and importer countries to proxies for the size of the economy of the country conducting bilateral trade at time t; DIS_{ij} is a variable describing the distance between two countries conducting bilateral trade; $RSCA_{ij}^t$ is the revealed symmetric comparative advantage, which is an index of the competitiveness of Indonesian fishery commodities in the international market at time t. The value of the RSCA was generated from the calculation of the RCA (Balassa, 1965) and RSCA (Laursen, 2015), which was calculated as follows:

$$RCA_{ij} = {}^{x_{ij}/x_i}\Big/_{X_{wj}/X_w} \quad \text{(Eq.9)}$$

$$RSCA_{ij} = {}^{RCAij - 1}\Big/_{RCAij + 1} \quad \text{(Eq.10)}$$

where x_{ij} is the export value of the j[th] product in the i[th] country or region; x_i is the total export volume of all products in the i[th] country or region; X_{wj}j is the total output of the j[th] product in the world and X_w is the total export value of all products in the world. Furthermore, $EXRATEINDO_{ij}^t$ is the variable exchange rate of the Indonesian rupiah against the US Dollar as one of the currencies in international trade in year t; CPI_j^t is the importing country (EU) consumer price index variable in year t.

Based on the results of parameter estimation, this study calculated the technical efficiency using the equation (developed by Battese and Coelli, 1988 and Coelli et al., 1998) as follows:

$$E[exp(-u_{ijt})|v_{ijt} + u_{ijt}] = \left[\frac{1-\Phi[\sigma_\alpha + \gamma(v_{ijt}+u_{ijt})/\sigma_\alpha}{1-\Phi\gamma(v_{ijt}+u_{ijt})/\sigma_\alpha}\right] \times exp\left[\gamma(v_{ijt} + u_{ijt}) + \frac{\sigma_\alpha^2}{2}\right] \quad \text{(Eq.11)}$$

Using this equation model, the technical efficiency can be estimated for each importing country with a value between 0 and 1. The value of technical efficiency is equal to 1, therefore, actual and potential trades are the same. If the efficiency value is close to 0, then the actual trade is below the potential trade level. This creates opportunities for exporting countries to increase their trade (Ahmad Hamidi et al., 2022). The export potential can be assessed using the following equation (Xu et al., 2023):

$$Potential\ export_{ijt} = \frac{Actual\ export_{ijt}}{Export\ efficiency_{ijt}} \quad \text{(Eq.12)}$$

Type and source of data

This study utilized panel data describing trade in Indonesian fishery products to the EU-27 countries in 2003–2021 (19 years). This study used HS 03, which were products from fish and crustaceans, mollusks, and other aquatic invertebrates. After analyzing the trade data on Indonesian fishery products on the EU market, 25 EU countries were selected as samples in this study. This was due to data limitations. A more detailed description of variables, sources, references, and signs expected in the SFGM model can be found in Table 1.

Table 1. Variables in the SFGM model.

Variable explanatory	References	Unit	Source of data
$EXPORT_{ij}^{t}$	(Abdullahi et al., 2021b; J. Xu et al., 2022)	US$	Trade Map (2023)
GDP_{i}^{t}	(Ebaidalla and Ali, 2022; Jiang et al., 2022b; Supriana et al., 2022)	US$	World Bank (2023)
GDP_{j}^{t}	(Ebaidalla and Ali, 2022; Jiang et al., 2022b; Supriana et al., 2022)	US$	World Bank (2023)
DIS_{ij}	(Ebaidalla and Ali, 2022; Jiang et al., 2022b; Supriana et al., 2022)	Km	UNESCAP (2023)
$RSCA_{ij}^{t}$	(Supriana et al., 2022)	Index	Author's calculation
$EXRATEINDO_{ij}^{t}$	(Abdullahi et al., 2021b; Atif et al., 2017b)	Rp/US$	World Bank (2023)
CPI_{j}^{t}	-	Index	World Bank (2023)

Results and Discussion

The export performance of Indonesian fishery products in the European Union market

During the 2003–2021 period, Indonesia's export performance of fishery products in the EU market showed a negative trend (Figure 3). The highest decline in this period was recorded in 2019. The corrected growth of exports of fishery products in 2019 was -23%, with an export value of only US$ 177,807,000. The year of 2019 was the start of COVID-19. COVID-19 was a major problem for world trade. This condition is in line with the research conducted by Cao et al. (2021) and Demirci et al. (2020). According to Cao et al. (2021), COVID-19 has a negative effect on trade in the majority of agricultural products due to disruptions in the supply chain. This condition is also confirmed by the results of the research conducted by Demirci et al. (2020). The negative impact of COVID-19 on trade in agricultural products on international markets could reach 65%. The short-term crisis in the fisheries sector caused by COVID-19 will be followed by long-term impacts (Amaralal et al., 2023). Therefore, special policies were needed to improve the performance of Indonesian fisheries in the EU market.

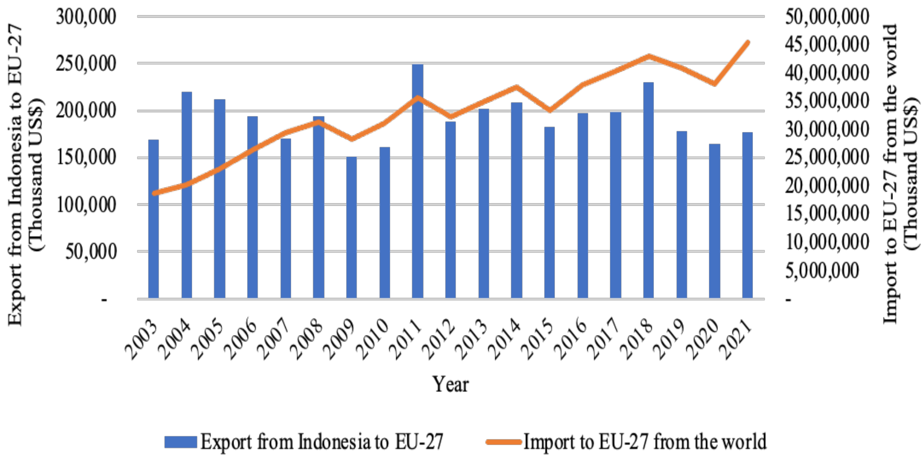

Figure 3. The export value of Indonesian fishery products to the EU market (thousand US$ in current price).

On the other hand, imports of fishery products from EU countries showed a positive trend in 2003–2021 (Figure 3). This condition illustrated that the need for fishery products in the EU market was still very high. EU imports of fishery products returned to higher levels compared to the previous year following the COVID-19 shock. The import value of EU fishery products reached US$ 45,400,394,000 in 2021. Hopefully, Indonesia's exports will increase in the following year and follow the trend of imports of fishery products to the EU.

Indonesia's fishery exports to the EU market consisted of 5 main commodities, namely shrimp, mollusks, fish fillets, frozen fish, and live fish (Figure 4). These five commodities formed the backbone of Indonesia's fishery exports to the EU market. The development of this industry could increase the trade of Indonesian fishery products in the international market. Shrimp had the largest export value with an average value of US$ 64,022,150.

Factors affecting exports of Indonesian fishery products to the EU market

The SFGM model in this study used the maximum likelihood estimator (MLE). The estimation results are shown in Table 2.

Table 2. Results of SFGM parameter estimation.

Variables	Coefficient	Std-error	p-value
Const	-29.68	3.49	0.000*
Ln GDPit	0.34	0.09	0.000*
Ln GDPjt	1.03	0.06	0.000*
Ln DISij	-0.30	0.11	0.006*
RSCA	2.23	0.06	0.000*
EXRATEINDO	1.19	0.19	0.000*
CPIj	-0.01	0.00	0.248
σ_{α}^{2}	1.12	0.37	0.000*
γ	0.86	0.05	
μ	1.93	0.38	0.000*
η	-0.03	0.00	0.000*

In order to test the strength of the SFGM in explaining the factors affecting exports of Indonesian fish products to the EU market, a test phase was required. First, the value of the coefficient γ, which was close to 1 (0.86), meant a random proportion in output, which was explained by the effect of inefficiency or differences in technical efficiency (Ogundari, 2008). This also strengthens the claim that the SFGM built has been able to explain variations in exports of Indonesian fishery products to the EU market (Vinh, 2022). Second, a statistically significant value of σ_{α}^{2} indicates that the model has fulfilled the due diligence test (Tandra et al., 2021).

The SFGM estimation results revealed that the main variable in the gravity model had a significant influence on the exports of Indonesian fishery products to the EU market. The GDP of the exporting country and the GDP of the importing country had a positive influence on the exports of fishery products to the EU market. Countries having a larger GDP value usually have more traded products (Abdullahi et al., 2022). The results of this study are in line with the research conducted (Handoyo, 2019; Khaliqi et al., 2018; Xu et al., 2023). The parameter coefficients obtained from the estimation results showed that a 1% increase in the GDP of the exporting country and the GDP of the importing country increased Indonesia’s fishery commodity exports to the EU by 0.34% and 1.03%, respectively.

The GDP of the exporting country and the GDP of the importing country had a positive effect, while distance had a significant but negative effect. The negative effect generated by distance is in accordance with the gravity model created earlier. In this case, according to Tinbergen (1962), distance has a negative effect on bilateral trade between countries. The farther the distance between the two countries conducting trade, the greater the trade costs incurred, which results in a decrease in the value of exports (Ahmad Hamidi et al., 2022). The findings of the parameter coefficients indicated that as the distance between the countries increased, the exports of the two countries decreased. Specifically, Indonesian exports of fishery products are expected to fall by 0.3% if the distance increases by 1%. The value of the change caused by an increase in trade costs was found to be relatively small because the effect of the change on the decline in Indonesia's fishery exports to the EU market was less than 1%. These results are in line with research conducted by Abdullahi et al. (2021a), Abdullahi et al. (2021b), Ahmad Hamidi et al. (2022) and Supriana et al. (2022).

This study also included other variables outside the main gravity model variables. The researcher added the RSCA, EXRATEINDO and CPI variables. The RSCA stands for the competitiveness of a traded product. The more competitive a product is in the market, the more frequently this product is traded (Dhamira et al., 2021; Suhana et al., 2016). The results of the study demonstrated that the RSCA had a significant positive effect on the exports of Indonesian fishery products to the EU market. The regression coefficient showed that an increase in product competitiveness would increase exports of Indonesian fishery products to the EU by 2.23%. The competitiveness of Indonesian fishery products in the EU market had a positive trend. This was illustrated by the increase in Indonesia's market niche in the EU market, which increased year by year. These results are in line with the research conducted by Supriana et al. (2022).

The rupiah exchange rate against the US dollar was also variable in this study. The results of this research are in line with research of Tandra et al. (2021), who state that the depreciation of the rupiah against the US dollar will increase export competitiveness. This is due to the depreciation of the national currency, which makes the price of exported goods cheaper compared to competing countries with stronger currencies. An increase in the rupiah exchange rate against the US dollar by 1% would increase exports of Indonesian fishery products to the EU by 1.19%. In addition, the consumer price index (CPI) of the importing country had no effect on Indonesia's fishery exports to the EU market.

Efficiency and export potential of Indonesian fishery products in the EU

Furthermore, this study calculated the value of technical efficiency (TE) based on the SFGM developed to analyze the exports of Indonesian fishery products to the EU market. The results of the TE values (Table 3) were the average values of all samples in 2003–2021. The calculation results show that Indonesia did not have an efficiency value of 100%. This condition illustrates that Indonesia and the EU countries have not carried out trade optimally (Ahmad Hamidi et al., 2022). The existence of trade barriers in the form of tariff and non-tariff policies can be the reason why the flow of trade in Indonesian fishery products has not reached the maximum conditions (Khaliqi et al., 2018; Thuong, 2018).

Table 3. The TE value of Indonesia's fishery product exports to the EU market.

No.	Country	TE	No.	Country	TE
1	Netherlands	85.83	14	Denmark	11.10
2	Belgium	65.09	15	Germany	11.20
3	Estonia	52.71	16	Hungary	9.33
4	Cyprus	45.69	17	Finland	9.70
5	Slovenia	40.76	18	Lithuania	8.42
6	Malta	30.09	19	Czech Republic	8.33
7	Spain	26.59	20	France	7.98
8	Portugal	19.46	21	Sweden	6.20
9	Italy	17.79	22	Romania	4.99
10	Greece	14.30	23	Ireland	4.66
11	Croatia	12.72	24	Slovakia	3.42
12	Poland	13.85	25	Austria	2.10
13	Bulgaria	11.17			

Table 4. Potential exports and GAP of Indonesian fishery products in the EU market (US$ million).

Importing country	Actual	Potential	GAP	Importing country	Actual	Potential	GAP
France	40.13	502.71	-462.58	Ireland	0.25	5.37	-5.12
Italy	45.69	256.80	-211.11	Netherlands	21.42	24.96	-3.54
Germany	19.21	171.51	-152.30	Croatia	0.45	3.57	-3.12
Austria	1.62	77.00	-75.38	Romania	0.11	2.14	-2.03
Spain	16.40	61.67	-45.27	Cyprus	1.56	3.40	-1.85
Sweden	1.89	30.49	-28.60	Lithuania	0.13	1.57	-1.44
Greece	4.63	32.40	-27.77	Hungary	0.08	0.88	-0.80
Denmark	3.41	30.75	-27.33	Malta	0.31	1.05	-0.73
Portugal	6.50	33.40	-26.90	Slovakia	0.02	0.54	-0.52
Poland	2.52	18.22	-15.69	Bulgaria	0.06	0.50	-0.44
Belgium	23.26	35.73	-12.48	Slovenia	0.25	0.62	-0.37
Czech Republic	1.12	13.41	-12.29	Estonia	0.11	0.20	-0.10
Finland	0.62	6.35	-5.73				

The export efficiency of Indonesia in the European Union (EU) market during the period of 2003–2021 averaged at 20.93%, which is relatively low compared to global benchmarks in similar studies. For instance, a study conducted by Baniya et al. (2020) on China's Belt and Road Initiative revealed that China's trade efficiency in key European markets often surpassed 60%. This highlights Indonesia's inefficiency in its main export commodities within the EU. Therefore, it is critical for Indonesia to improve its export efficiency to enhance its market niche. Notably, five countries demonstrated relatively high export efficiency scores: the Netherlands (85.83%), Belgium (65.09%), Estonia (52.71%), Cyprus (45.69%), and Slovenia (40.76%). These countries are key access points for Indonesian exports within the EU, aligning with the findings of Ravishankar and Stack (2014), who emphasize the importance of targeting highly efficient markets to optimize trade potential. Conversely, the countries with the lowest efficiency scores are Sweden (6.20%), Romania (4.99%), Ireland (4.66%), Slovakia (3.42%), and Austria (2.10%). Kalirajan and Bhattacharya (2008) also came to similar conclusions, stating that inefficiencies in certain markets can be attributed to tariff barriers and infrastructural limitations.

The evaluation of the export potential of Indonesian fisheries in the EU market is presented in Table 4, using Equation 11 to obtain the corresponding values. Among the EU countries, France, Italy, Germany, Austria, and Spain show the largest discrepancies between the actual and potential exports of Indonesian fishery products. This observation aligns with Jiang et al. (2022c), who have noted that the presence of a significant export gap indicates untapped trade potential that can be harnessed through targeted trade facilitation measures. The underutilization of Indonesia's fisheries trade in the EU is reminiscent of the inefficiencies in China's exports to emerging markets identified by Tan and Zhou (2015) and highlights the need for a strategic approach. This finding emphasizes the need for Indonesia to focus on key EU markets to enhance efficiency and optimize the use of existing trade potential, ultimately maximizing fishery exports.

Conclusion

This study estimated the factors affecting exports of Indonesian fishery products to the EU market using the SFGM and the MLE, estimated the efficiency value of Indonesian fishery product exports to the EU market, and analyzed the export potential of Indonesian fishery products to the EU market in the 2003–2021 period. The model suitability test was carried out in two stages. First, the value of the gamma coefficient close to 1 (0.86) meant a random share of production, which was explained by the effect of inefficiency or the difference in technical efficiency. Second, a statistically significant value of σ_{α}^{2} indicated that the model had fulfilled the due diligence test. The estimation results showed that the GDP of the exporting country, the GDP of the importing country, competitiveness (RSCA) and the exchange rate of the rupiah against the US dollar had a positive effect on the exports of fishery products to the EU market. On the other hand, the distance proxied using trade costs showed a negative effect on Indonesia's fishery exports to the EU market. In addition, we did not have sufficient evidence to show the effect of the consumer price index on Indonesia's fisheries exports.

Indonesia's average export efficiency in the EU market was 20.93% in the 2003–2021 period, reflecting substantial underperformance relative to its potential. This inefficiency stems from several factors, including structural weaknesses in Indonesia's trade infrastructure, such as inadequate port facilities, inefficient customs processes, and logistical barriers that increase costs and reduce competitiveness. Additionally, Indonesia's export portfolio is focused on low-value, labor-intensive goods, limiting its ability to compete in the higher-value EU markets. Trade policy misalignments, including high tariffs and non-tariff barriers in key EU markets, further exacerbate these inefficiencies, hindering Indonesia's ability to leverage its comparative advantages, particularly in fisheries.

Indonesia must modernize its trade infrastructure, including ports and transportation networks, to lower trade costs and enhance the reliability of exports. Streamlining customs and regulatory processes is also vital for improving export efficiency. Diversifying the export base by moving up the value chain and investing in higher-value-added goods demanded in the EU is essential. This can be achieved by promoting innovation and technology adoption in key sectors like fisheries and manufacturing. Additionally, the government should negotiate more favorable trade agreements with the EU to reduce tariffs and other trade barriers. Targeted support should be provided to high-potential but currently inefficient industries, such as fisheries, to bridge the gap between actual and potential export performance.

This study offers useful information regarding the factors that influence the Indonesian fishery industry exports to the EU. However, it has limitations due to its reliance on data from 2003 to 2021, which may not fully represent the consequences of more recent global economic changes. Additionally, the research is confined to the EU market, and the outcomes might not be applicable to other regions. Future investigations could extend the time frame to encompass more recent data and explore additional significant export markets, such as the United States or East Asia. Furthermore, a more in-depth, product-specific analysis within the fisheries sector and the integration of qualitative approaches, such as interviews with industry stakeholders, could offer a more refined comprehension of the difficulties and opportunities encountered by Indonesian exporters.

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POVEĆANJE EFIKASNOSTI I POTENCIJALA IZVOZA INDONEŽANSKIH RIBARSKIH PROIZVODA NA TRŽIŠTE EVROPSKE UNIJE

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R e z i m e

Očekuje se da će sporazum o slobodnoj trgovini (engl. *free trade agreement* – FTA) između Indonezije i EU podstaći ekonomski rast Indonezije, posebno u oblasti trgovine. Međutim, od 2020. do 2022. godine, zemlje EU su izdale 38 dopisa u vezi sa izvozom iz Indonezije, pre svega u vezi sa sanitarnim i fitosanitarnim merama, koje predstavljaju necarinske barijere u slobodnoj trgovini. Indonezija nije imala koristi od povećanja uvoza ribarskih proizvoda u EU. Ova studija se bavi nedostacima u istraživanju efikasnosti i izvoznog potencijala ribarskih proizvoda iz Indonezije na tržište EU. Cilj je da se procene faktori koji utiču na tok trgovine, efikasnost izvoza i potencijal izvoza indonežanskih ribarskih proizvoda u EU koristeći stohastički granični gravitacioni model (engl. *stochastic frontier gravity model – SFGM*). Stohastički granični gravitacioni model u gravitacionom modelu određuje maksimalni potencijalni obim razmene koji se može postići u bilateralnoj trgovini. U ovom istraživanju su korišćeni panel podaci o indonežanskom izvozu ribarskih proizvoda u 27 zemalja članica EU od 2003. do 2021. godine (19 godina). U ovoj studiji analizirani su proizvodi HS klasifikacije 03 ribe, ljuskari, mekušci i ostali vodeni beskičmenjaci koji su izvezeni iz Indonezije u 25 zemalja EU. Rezultati su pokazali da su BDP i zemalja izvoznica i zemalja uvoznica, konkurentnost i kurs rupije u odnosu na američki dolar pozitivno uticali na izvoz ribarskih proizvoda u EU. Nasuprot tome, udaljenost, predstavljena troškovima razmene, negativno je uticala na izvoz ribarskih proizvoda iz Indonezije u EU. Rezultati su pokazali da Indonezija nije ostvarila efiksnost na nivou od 100%. Najveći tržišni potencijal Indonezije u EU ogledao se u izvozu ribarskih proizvoda u Francusku, Italiju, Nemačku, Austriju i Španiju.

Ključne reči: izvoz, Evropska unija, ribarstvo, Indonezija, spoljnotrgovinska efikasnost, trgovinski potencijal.

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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

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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.

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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 200 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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