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NORDIC FIELD TRIAL NETWORK

SEM analysis of the effect of biostimulants on potato yield and nutrient use efficiency

4th NFTN Conference 2026

Philipp Trénel, Lead Data Scientist, Ph.D.
Danish Technological Institute
phtr@teknologisk.dk

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Why biostimulants?

- There is a **need** for **sustainable agricultural food production systems** with less input of nutrients and chemicals

- Biostimulants might be **one** of **several solutions**

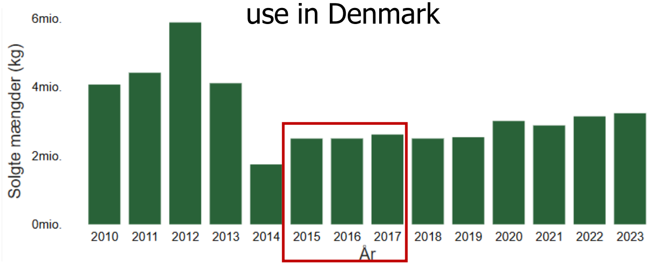
- but evidence on the effectiveness of biostimulants remain **scarce** and **ambiguous**

(Mannino et al., 2025)

European Commission

The EU's Green Deal is targeting a reduction of pesticide use and risk by 50% by 2030.

Yearly total pesticide use in Denmark



Reference for Green Deal targets

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What are biostimulants?

According to Regulation (EU) 2019/1009:

- "**Substances, mixtures and micro-organisms** (products) that aim solely at **improving** the plants' **nutrient use efficiency**, **tolerance** to **abiotic stress**, **quality traits** or increasing the **availability** of confined **nutrients** in the soil or rhizosphere".

- "Products that act in addition to fertilizers, with the aim of **optimizing** the **efficiency** of those fertilizers and **reducing** the **nutrient application rates**".

See more at:

Plant Biologicals Network

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There is a clear **need** for:

- development of **new test tools & protocols**
- addressing the complex, multi-variable **Mode-of Action** (MoA) claims of biostimulants
- via **impartial testing** of **producer claims** of biostimulant products

Claimed multi-functional benefits of biostimulants

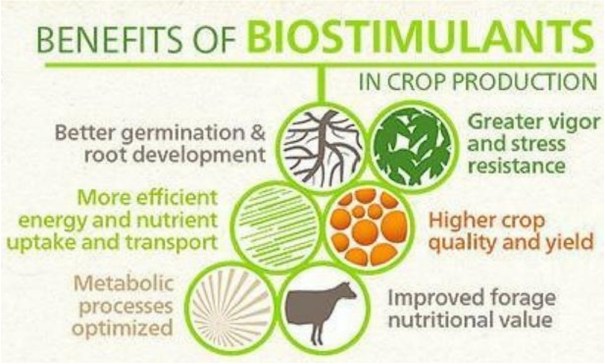

Figure by Alltech

1. Better germination & root development
2. More efficient nutrient utilization (NUE)
3. Optimized metabolic processes
4. Greater vigor and stress resistance
5. Higher crop quality and yield
6. Improved nutritional value of the crop

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Aim

- By utilizing a **Structural Equation Model (SEM)** approach for **testing hypotheses of claimed mode-of-actions** (MoA) of the five biostimulants

  Acadian, *CropSet*, *Humifirst*, *Proradix*, and *Vesta,*

- we investigated biostimulant effects on **potato yield**, yield **quality**, **nutrient use efficiency** (NUE), and **soil enzyme activity**.

- We did this by combining data from **two Danish organic potato field trials** conducted within the GUDP-project BioGrowth.

Ministeriet for Fødevarer, Landbrug og Fiskeri

gudp

BioGrowth (Ministry of Food, Agriculture & Fisheries GUDP) - Biostimulants for improved growth and quality of field vegetables

Edelenbos, Merete (PI), Kristensen, Hanne Lakkenborg (Deltager), Gebremikael, Mesfin Tsegaye (Deltager)

Institut for Fødevarer - Fødevareteknologi, Institut for Fødevarer - Planter, Fødevarer & Bæredygtighed

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Road map for our SEM approach

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1) Producer claims

↓

2) Turning claims into testable endpoints

↓

3) Connect endpoints into a MoA hypothesis network

↓

4) Setup SEM model in line with MoA hypothesis

5) Compile trial data

↓

6) Do SEM analysis

↓

7) Results

1) Producer claims

	Acadian	**Crop-Set**	**Humifirst**	**Proradix**	**Vesta**
Biostimulant Type	Seaweed extract	Fermentation-based + micronutrients	Humic–fulvic acid	Microbial with biocontrol functions	Microbial
Key composition	Seaweed (*Ascophyllum nodosum*) extracted with potassium hydroxide. The extract contains biactive acids produced by algae, polysaccharides including fucose, mannitol, monosaccharides, amino acids, organic acids, betaines, and macro- and micro nutrients (Zn, Mg, Fe).	A mixture of yucca palm extract (*Yucca schidigera*), a bacterial fermented extract without alive bacteria, and addition of sulfur sulfate (1.2% S), copper sulfate (0.2% Cu), iron sulfate (0.6% Fe), and manganese (1.5% Mn)	Extract of humic (12 %) and fulvic acids (3 %) made from American Leonardit	Powder containing *Pseudomonas sp.* DSMZ 13134	Suspension of >5,400 living microorganisms extracted from fermented seaweed, microbial metabolites, and humic extract.
Main Effects	Increased root growth and improved plant establishment. Improved plant vigor and plant growth enhancing yield and crop quality.	Improves nutrient uptake and partitioning, and stimulates plant metabolic processes (root growth, vegetative growth, reproductive growth) through greater availability of essential nutrients. Improves crop vigor, yield and marketable yield, including crop uniformity,	Improves soil aggregation and ICEC, and germination and root growth. Improves nutrient uptake (P, Fe, Mn, Zn, Cu). Increases root and plant growth, enhancing yields and crop quality.	Improves root growth, which improves the nutrient use efficiency. Improves plant and crop growth, enhancing yield and crop quality. Controls silver scab, and stem canker and black scurf caused by *Rhizoctonia solani*	Restores soil microbiology and increases root growth. Increases nutrient cycling efficiency and improves nutrient use efficiency. Increase plant vigor and uniformity.
Stress Tolerance Effects	Enhances tolerance to drought and cold stress, linked to upregulation of defence-related genes and pathways in the plant.	Improves performance under in-season stress. The plant extract activates the plant defence mechanisms, increases photosynthetic pigments and gas exchange under drought stress	Increases resistance to drought, salinity, and cold stress as a result of increased enzymatic and non-enzymatic defence, increased compatible solute production, and changed ion balance.	Enhances abiotic stress response via induced systemic resistance induction	Increased tolerance to heat and water stress. Improved photosynthesis.
Reference/link	https://acadianplanthealth.com/your-crops/vegetables/potatoes/ https://explore.azelis.com/en_GB/nor_ag/azelis-seaweed-in-cucumber-tomato	https://www.bj-agro.dk/salg/crop-set https://www.alltech.com/en/our-solutions/crop-science/performance	https://www.n-xt.com/en/products/tradecorp-products/humifirst%C2%AE-	https://en.sourcon-padena.de/linee/line-plant-protection-product/cat-agrofarmaco/proradix-united-kingdom.html	https://sovitae.com/products/

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2) Turning claims into testable endpoints

<table>
<tr><th colspan="2">Claimed beneficial effect</th><th rowspan="2">Endpoint indicator</th><th colspan="5">Biostimulant</th></tr>
<tr><th>Group</th><th>Subgroup</th><th>Acadian</th><th>CropSet</th><th>Humifirst</th><th>Proradix</th><th>Vesta</th></tr>
<tr><td colspan="2">Microbial soil health</td><td>DHA/BGA</td><td></td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><td colspan="2">Root growth</td><td>Not assessed</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="2">Plant growth & vigor</td><td>Fv/Fm</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="2">Plant stress resistance</td><td>Not assessed</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="2">Nutrient use efficiency</td><td>PFPn, PFPp</td><td></td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="2">Yield</td><td>NTTY</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td rowspan="4">Quality</td><td>Marketable yield[1]</td><td>Prop. marketable[1]</td><td rowspan="4">X</td><td>X</td><td rowspan="4">X</td><td rowspan="4">X</td><td></td></tr>
<tr><td>Yield uniformity</td><td>VAR (NTTY)</td><td></td><td></td></tr>
<tr><td rowspan="2">Storage stability</td><td>Prop(Tubers > 6 cm) (TS)</td><td></td><td></td></tr>
<tr><td>Total sugar content (SC)</td><td></td><td></td></tr>
<tr><td colspan="3">Number of testable claims in the current study</td><td>3</td><td>4</td><td>5</td><td>4</td><td>3</td></tr>
</table>

[1]Marketable yield = NTTY * (100 - mechanical damage% + disease damage%) / 100
In the current data, disease damage% ≫ mechanical damage%, and, hence, total disease damage% (**TDD**) was used as endpoint.

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Some definitions

DHA

”Dehydrogenase enzyme activity (DHA) is considered as the indicator of oxidative activity of soil microorganisms and increases significantly upon application of balanced fertilization.”

BGA

”β-glucosidase (BGA) is involved in catalyzing the hydrolysis and biodegradation of various β-glucosides that are present in plant debris. … β-glucosidase’s involvement in C cycling has remarkably facilitated its adoption for soil quality testing.”

https://www.researchgate.net/publication/320388949_The_biological_activities_of_b-glucosidase_phosphatase_and_urease_as_soil_quality_indicators_A_review

F_v/F_m

“Fv/Fm tests whether or not plant stress affects photosystem II in a dark adapted state.”

https://en.wikipedia.org/wiki/Plant_stress_measurement

PFP

Partial factor productivity

”This is the ratio of crop yield to fertilizer nutrient applied. It indicates the productivity per unit of fertilizer input.”

PFPn = PFP for nitrogen
PFPp = PFP for P

IUE

Internal use efficiency

”This is the ratio of crop yield to nutrient content in harvested parts. It indicates the efficiency of economic product formation per unit of removed nutrient. A high IUE means a high yield with low nutrient concentration in harvested parts.”

IUE(N) ≈ protein content

https://geopard.tech/blog/defining-nutrient-use-efficiency-in-responsible-plant-nutrition/

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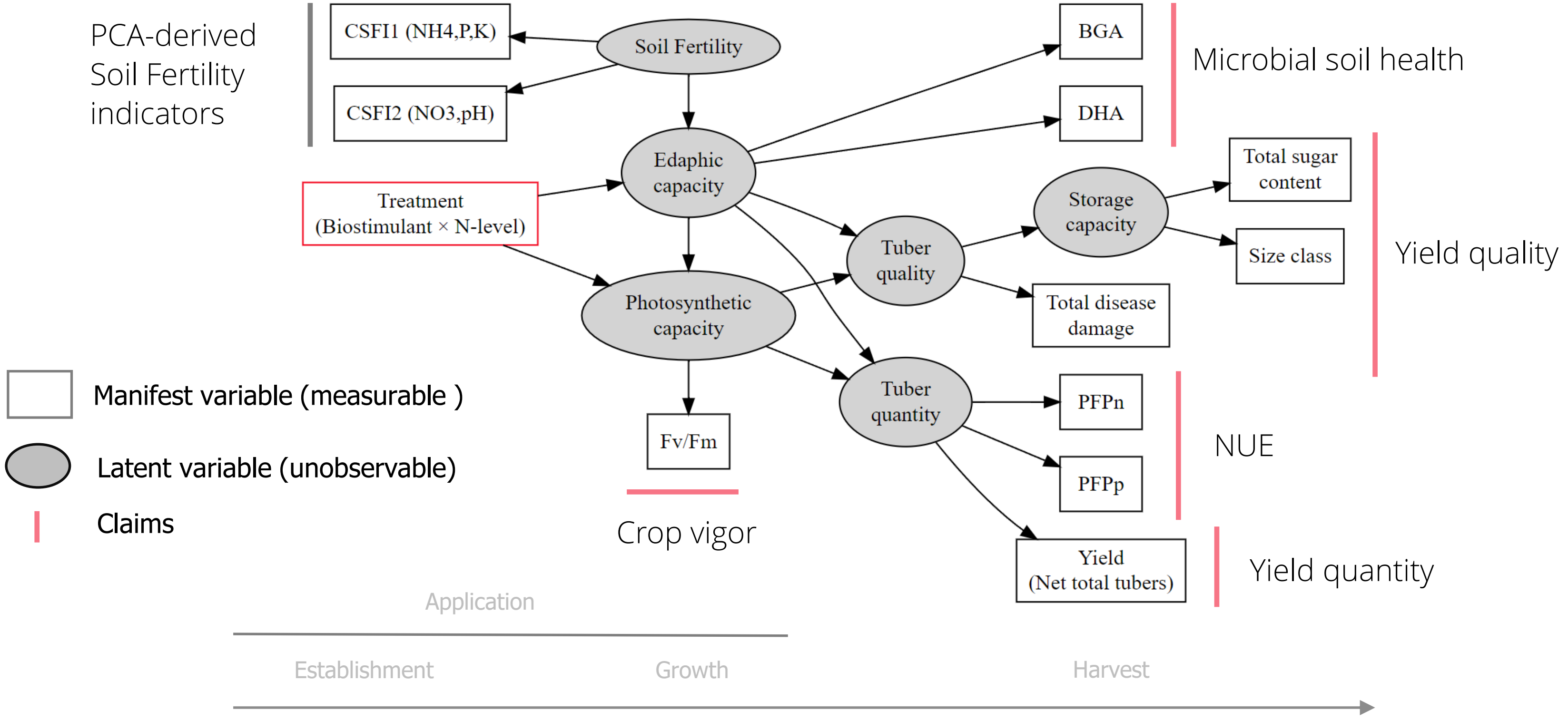
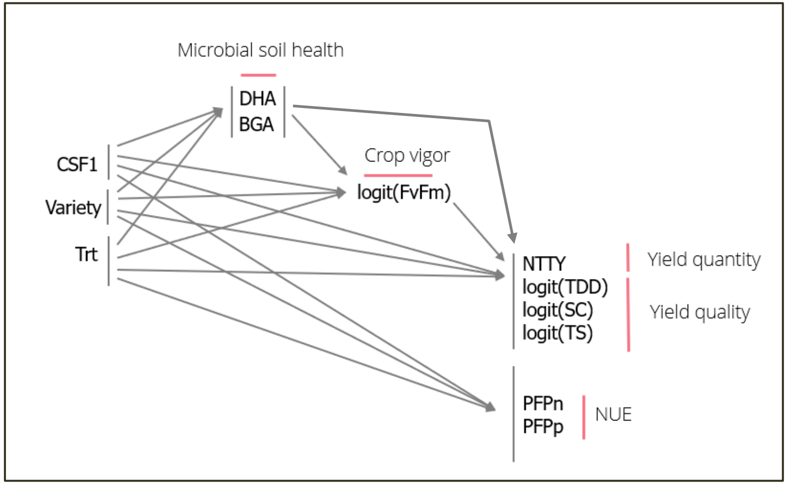
3) Connect endpoints into a MoA hypothesis network



4) Setup SEM model in line with MoA hypothesis



(1) $DHA_i = \beta_{1,0} + \beta_{1,1}CSFI1_i + \beta_{1,2}Variety_i + \beta_{1,3}Trt_i + D_i$

(2) $BGA_i = \beta_{2,0} + \beta_{2,1}CSFI1_i + \beta_{2,2}Variety_i + \beta_{2,3}Trt_i + D_i$

(3) $logit(F_v/F_m)_i = \beta_{3,0} + \beta_{3,1}CSFI1_i + \beta_{3,2}Variety_i + \beta_{3,3}DHA_i + \beta_{3,4}BGA_i + \beta_{3,5}Trt_i + D_i$

(4) $NTTY_i = \beta_{4,0} + \beta_{4,1}CSFI1_i + \beta_{4,2}Variety_i + \beta_{4,3}DHA_i + \beta_{4,4}BGA_i + \beta_{4,5}logit(F_v/F_m)_i + \beta_{4,6}Trt_i + D_i$

(5) $logit(TDD)_i = \beta_{5,0} + \beta_{5,1}CSFI1_i + \beta_{5,2}Variety_i + \beta_{5,3}DHA_i + \beta_{5,4}BGA_i + \beta_{5,5}logit(F_v/F_m)_i + \beta_{5,6}Trt_i + D_i$

(6) $logit(SC)_i = \beta_{6,0} + \beta_{6,1}CSFI1_i + \beta_{6,2}Variety_i + \beta_{6,3}DHA_i + \beta_{6,4}BGA_i + \beta_{6,5}logit(F_v/F_m)_i + \beta_{6,6}Trt_i + D_i$

(7) $logit(TS)_i = \beta_{7,0} + \beta_{7,1}CSFI1_i + \beta_{7,2}Variety_i + \beta_{7,3}DHA_i + \beta_{7,4}BGA_i + \beta_{7,5}logit(F_v/F_m)_i + \beta_{7,6}Trt_i + D_i$

(8) $PFPn_i = \beta_{8,0} + \beta_{8,1}CSFI1_i + \beta_{8,2}Variety_i + \beta_{8,3}Trt_i + D_i$

(9) $PFPp_i = \beta_{9,0} + \beta_{9,1}CSFI1_i + \beta_{9,2}Variety_i + \beta_{9,3}Trt_i + D_i$

$where\ \ D_i = Year \times Location \times Block_{j[i]} + e_i$

$Year \times Location \times Block_j \sim N(0, \sigma_b^2)$

$e_i \sim N(0, \sigma_e^2)$

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5) Compile trial data

	Trial 1	Trial 2
Locality	Årslev	Auning
Year	2021	2022
Soil properties	Mean (SD)	
mineral N, kg/ha	27.38 (1.70)	28.35 (6.90)
P, kg/ha	135.98 (18.91)	75.08 (1.86)
pH	6.35 (0.05)	6.19 (0.10)
Variety	Arielle	Belana (Arielle)
N-levels	N100 + N50	N100 + N50
Trial design	2-factorial RCBD[1]	3-factorial RCBD
Factorial structure	**Factor 1 (F1)**: Biostimulant {Control, Acadian, CropSet, Humifirst, Proradix, Vesta, CombiSet} **Factor 2 (F2):** Nitrogen level {norm N-level (100%), reduced N-level (50%)}	**Factor 1 (F1):** Biostimulant {Control, Acadian, CropSet, Humifirst, Proradix, Vesta, CombiSet} **Factor 2 (F2):** Nitrogen level {norm N-level (100%), reduced N-level (50%)} Factor 3 (F3): Variety {Belana : F1×F2, Arielle : (F1=Control)×F2}
Effective number of replicates (Ctrl)	3 (3)	4 (8)

[1]RCBD: Randomized Complete Block Design

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6) Do SEM analysis

	I		***II***	
	n = 39		n = 67	
	Variety (Trial1/Trial2)			
Arielle	18/0		18/7	
Belana	0/21		0/42	
	N-level (Trial1/Trial2)			
N100	18/21		18/24	
N50	0/0		0/25	
	Overall goodness of fit			
Fisher's C (df)	62,182 (66)		32,04 (36)	
P-value	0,610		0,657	
	Component model goodness of fit			
Response	Marginal R^2	Conditional R^2	Marginal R^2	Conditional R^2
logit(FvFm)	0,48	0,48	0,35	0,35
NTTY	0,77	0,84	0,75	0,85
logit(TDD)	0,38	0,45	0,48	0,48
DHA	0,66	0,71	0,68	0,79
BGA	0,63	0,63	0,56	0,63
PFPn	0,60	0,69	0,81	0,87
PFPp	0,20	0,41	0,68	0,80
logit(SC)	0,82	0,83	-	-
logit(TS)	0,90	0,90	-	-

7) Results

Claimed beneficial effect: Group	Subgroup	Endpoint indicator	Estimated Cohen's *d* effect sizes [3]: Acadian	CropSet	Humifirst	Proradix	Vesta	Note
Microbial soil health		DHA	0.47 (N50)[II]	0.05 (N50)[II]	0.23 (N50)[II]	-0.02 (N100)[I]	**0.62+** (N50)[II]	High is good
		BGA	0.08 (N100)[I]	**0.72*** (N100)[I]	0.17 (N100)[I]	-0.11 (N100)[I]	-0.15 (N100)	
Plant growth & vigor		Fv/Fm	**1.46*** (N50)[II]	0.64 (N50)[II]	**0.61+** (N100)[I]	0.42 (N100)[I]	0.46 (N100)[I]	
Nutrient use efficiency		PFPn	0.36 (N100)[I]	**0.68*** (N100)[I]	0.08 (N100)[II]	**0.60+** (N100)[I]	0.15 (N100)[II]	
		PFPp	0.53 (N100)[I]	**1.00*** (N100)[I]	0.15 (N50)[II]	**0.76*** (N50)[II]	0.15 (N100)[II]	
Yield		NTTY	0.29 (N100)[I]	**0.62*** (N50)[II]	0.21 (N50)[II]	**0.70*** (N50)[II]	0.16 (N50)[II]	
Quality	Marketable yield[1]	TDD[1]	-0.66 (N50)[II]	**-0.69+** (N100)[II]	-0.49 (N50)[II]	**-1.19+** (N50)[II]	-0.40 (N50)[II]	Negative is good
	Yield uniformity	VAR (NTTY) [2]	1.11 (N100)[I]	**0.35+** (N50)[II]	0.42 (N50)[II]	0.92 (N100)[II]	0.80 (N100)[I]	Low is good
	Storage stability (N100)[I]	Prop(Tubers > 6 cm) (TS)	-0.05	0.26	0.05	**0.62***	-0.18	High is good
		Total sugar content (SC)	**-0.36***	**-0.41***	**-0.42***	**-0.73******	-0.24	Negative is good
# met / producer stated claims		p < 0.15	2 / 3 66%	3 / 4 75%	2 / 5 40%	3 / 4 75%	1 / 3 33%	
		Cohen's d > |0.5|	2 / 3 66%	4 / 4 100%	1 / 5 20%	3 / 4 75%	1 / 3 33%	
# found / possible beneficial effects		Cohen's d > |0.5|	3 / 5 60%	5 / 5 100%	1 / 5 20%	3 / 5 60%	1 / 5 20%	

+: $p < 0.15$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

[1]Marketable yield = NTTY * (100 - mechanical damage% + disease damage%) / 100

In the current data, disease damage% ≫ mechanical damage%, and, hence, total disease damage% (**TDD**) is used as endpoint.

[2]Var(NTTY) is evaluated as $Sd_{treatment} / SD_{control}$

[3]Cohen's $d = \hat{\beta} / SD(y)$, small effect: d = 0.20; medium effect: d = 0.50; large effect: d = 0.80

Producer claim

Significant after FDR correction

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Discussion & Conclusions

- **All five biostimulant products showed at least one significant beneficial treatment effect** at the un-corrected 0.15 significance level.

- However, after false-discovery-rate multiple testing correction, only a single effect remained significant; Proradix on *TS*. This clearly indicates that **statistical power should be a major concern**, when assessing the multi-variable MoA claims of biostimulants.

- **Products varied in how good they met their claims:** we found poor (20-33%; Humifirst, Vesta), moderate (66%; Acadian) to good (75-100%; Proradix and CropSet) agreement between SEM estimates and claims.

- **Significant yield improvements** were found for CropSet and Proradix, only.

- However, significant **improvement in storage stability**, measured as decreased total sugar content (TS), was found in 4 out of 5 products.

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Collaborators

Mesfin Tsegaye Gebremikael
Tenure Track Assistant Prof., Ph.D
Aarhus University
Department of Food Science
Plant, Food & Sustainability

Merete Edelenbos
Associate professor, Ph.D
Aarhus University
Department of Food Science
Plant, Food & Sustainability

Aarhus University, Department of Food Science · Gl. Estrup Gartneri – Grøntsags-Delikatesser, Kvalitet & Tradition · SeedCom · SOBEC® EMEA – Probiotics for the soil™ · BJ-Agro · azelis · HortiAdvice · MÅNSSON · Nordisk Alkali – member of the Belchim Group

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Ministeriet for Fødevarer, Landbrug og Fiskeri – gudp

Foreningen Plan Danmark

BioGrowth (Ministry of Food, Agriculture & Fisheries GUDP) - Biostimulants for improved growth and quality of field vegetables

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THANK YOU!

Contact: phtr@dti.dk