

# **A comprehensive study from cradle-to-grave on the environmental profile of malted legumes**

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**SUPPLEMENTARY MATERIAL S1**

**Table S1.1**

Description of the product stages involved in the dried pulse life cycle network according to the Simapro software used in this work.

<b>Product stage</b>		<b>Name</b>	<b>Main output</b>	<b>Unit</b>	<b>Ref. Table</b>
Process	1	Pulse cultivation	Fresh pulse grains	kg	Table S1.2
Process	2	AIP production	AIP	kg	Table S1.3
Process	3	Fumigated pulse grains	Fumigated pulse grains	kg	Table S1.4
Process	4	1-Mg PE FIBC production	SS	kg	Table S1.5
Process	5	FIBC-packed cleaned dried pulse grains	Packed pulse grains	kg	Table S1.6
Process	6	Ready-to-pack dried pulse grains	Ready-to-pack pulse grains	kg	Table S1.7
Process	7	PP bag production	PP bags	kg	Table S1.8
Process	8	Cardboard collar production	Cardstocks	kg	Table S1.9
Process	9	Brass rivet production	Rivets	kg	Table S1.10
Process	10	Adhesive paper label production	Paper labels	kg	Table S1.11
Process	11	Carton production	Cartons	kg	Table S1.12
Process	12	Scotch tape production	Scotch tape	kg	Table S1.13
Process	13	PP semipallet production	PP semipallet	kg	Table S1.14
Process	14	Shrink & shrank PE film production	PE film	kg	Table S1.15
Assembly	15	Assembly of the primary packaging for dried pulses	Ass 1pack	p	Table S1.16
Assembly	16	Assembly of the secondary packaging for dried pulses	Ass 2pack	p	Table S1.17
Assembly	17	Assembly of the tertiary packaging for dried pulses	Ass 3pack	p	Table S1.18
Assembly	18	Assembly of the primary and secondary packages for dried pulses	Ass 1-2pack	p	Table S1.19
Assembly	19	Assembly of the primary, secondary and tertiary packages for dried pulses	Ass 1-2-3pack	p	Table S1.20
Assembly	20	Assembly of dried pulses	Ass dried pulses	p	Table S1.21
Processes	21	Use phase	Cooked pulses	kg	Table S1.22
Waste scenario	22	Waste scenario of plastic packaging wastes	PLW	kg	Table S1.23
Waste scenario	23	Waste scenario of paper and cardboard packaging wastes	PCW	kg	Table S1.24
Waste scenario	24	Waste scenario of non-ferrous metal wastes	NFMW	kg	Table S1.25
End of life scenario	25	Disposal scenario of primary packaging material wastes	DS-1pack	-	Table S1.26
End of life scenario	26	Disposal scenario of secondary packaging material wastes	DS-2pack	-	Table S1.27
End of life scenario	27	Disposal scenario of the tertiary packaging wastes	DS-3pack	-	Table S1.28
End of life scenario	28	Disposal scenario of the I, II, and III packaging material wastes	DS-1-2-3pack	-	Table S1.29
Reuse	29	Reuse of the PP semi-pallet	Pallet reuse	p	Table S1.30
Life cycle	30	Life cycle of dried pulses	LC-DP	p	Table S1.31
Life cycle	31	Life cycle of the primary, secondary and tertiary packaging materials	LC1-2-3pack	p	Table S1.32
Life cycle	32	Life cycle of the PP semi-pallet	LC-3pack	p	Table S1.33

**Table S1.2**

Inventory associated with the *Solco Dritto* chickpea cultivation phase.

Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC- 1 grains		CropYield*1000 = 1.71E3	kg	Mass	100 %	Biopolymers	Agricult... \Market	Solco Dritto Chickpeas -	
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Occupation, annual crop, non-irrigated, intensive,			1	ha a	Undefined				
Water, river, IT			0	m3	Undefined				
Inputs from technosphere: materials/fuels		Sub-compartment	Amount	Unit	Distribut	SD2 or 2SD	Min	Max	Comment
NPK (15-15-15) fertiliser (RER)   market for NPK (15-15-15) fertiliser   Cut-off, S			NPKU*A = 133	kg					
Poultry manure, fresh (GLO)   market for poultry manure, fresh   Cut-off, S			PM*A = 200	kg					
Pesticide, unspecified (GLO)   market for pesticide, unspecified   Cut-off, S			DIS*A = 0.125	kg					
Lubricating oil (RER)   market for lubricating oil   Cut-off, S			LO*A = 1	kg					
Diesel combustion in agricultural machine (GLO)   diesel driven   production mix, at plant   30kW to 180kW   LCI result			DF*DDF*A = 88.8	kg					PCI042.6 MJ/kg: engineeringtoolt
SDC - seeds			0	kg	Unde				
SDC - Chickpea seeding Mass, S			Seed*A = 130	kg					
Inputs from technosphere: electricity/heat		Sub-compartment	Amount	Unit	Distribut	SD2 or 2SD	Min	Max	Comment
Transport, freight, light commercial vehicle (Europe without Switzerland)   market for transport, freight, light commercial vehicle   Cut-off, S			A*(Seed*25+NPKU*100+PM*100+DIS*25+DF*25+LO*25)/1000 = 39.2						
Transport, tractor and trailer, agricultural (CH)   market for transport, tractor and trailer, agricultural   Cut-off, S			CropYield*DISTCA = 4.28						
Outputs									
Emissions to air		Sub-compartment	Amount	Unit	Distribut	SD2 or 2SD	Min	Max	Comment
Dinitrogen monoxide			FN2O*A = 1.14	kg					
Nitrogen monoxide, IT			NO*A = 0.731	kg					
Carbon dioxide, fossil			0	kg	Unde				
Emissions to water		Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Nitrate, IT		river, long-term	FNO3*A = 13.1	kg					
Phosphorus, IT		river, long-term	PLEACH*A = 0.611	kg					

Documentation	Input/output	Parameters	System description				
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
CropYield	1.71	Triangle		1.11	2.35	<input type="checkbox"/>	Resa granella fresca [Mg/(ha a)]
NPK	100	Triangle		90	110	<input type="checkbox"/>	Fertilizzante NPK (20-20-20) [kg/ha]
PM	200	Triangle		180	220	<input type="checkbox"/>	Poltry manure (4-4-4) [kg/ha]
DIS	0.125	Normal	0.05			<input type="checkbox"/>	Herbicide [kg/ha]
DF	105	Triangle		90	120	<input type="checkbox"/>	Diesel Fuel [L/ha]
LO	1	Undefined				<input type="checkbox"/>	Lubricant Oil [L/ha]
A	1	Undefined				<input type="checkbox"/>	Area [ha]
FRACrenew	1	Undefined				<input type="checkbox"/>	Coltura annuale
RAG	2.1	Undefined				<input type="checkbox"/>	Residui superficiali/Crop
FRACremoved	0	Undefined				<input type="checkbox"/>	
FRACburned	0	Undefined				<input type="checkbox"/>	
SSCrop	0.88	Undefined				<input type="checkbox"/>	SS della granella raccolta [g/g]
NAG	0.008	Undefined				<input type="checkbox"/>	Frazione azoto nella biomassa sup [g/g]
NBG	0.008	Undefined				<input type="checkbox"/>	Frazione azoto nella biomassa radicale [g/g]
RBGBIO	0.19	Normal	0.07			<input type="checkbox"/>	SS in BG/SS in AG [g/g]
Aburnt	0	Undefined				<input type="checkbox"/>	Area ove si effettua l'incenerimento dei residui [ha]
Cf	0	Undefined				<input type="checkbox"/>	Fattore di combustione
FRACgasf	0.11	Triangle		0.02	0.33	<input type="checkbox"/>	kg N volatilizzato come NH3 e NOX/kg N sintetico applicato
FRACgasm	0.21	Triangle		0	0.31	<input type="checkbox"/>	kg N volatilizzato come NH3 e NOX/kg N organico applicato
EF4	0.01	Triangle		0.002	0.018	<input type="checkbox"/>	kg N2O-N/kg di NH3 e NOX volatilizzato
EF5	0.011	Triangle		0	0.02	<input type="checkbox"/>	kg N2O-N/kg di N lisciviato o dilavato
FPRP	0	Undefined				<input type="checkbox"/>	kg N nell'urina e sterco depositati da animali al pascolo [kg N/ha]

FSOM	0	Undefined				<input type="checkbox"/>	kg N mineralizzato nei suoli ove si verifica perdita di C nella sostanza organica [kg N/ha]
FRACleach	0.24	Triangle		0.01	0.73	<input type="checkbox"/>	kg N <sub>2</sub> O-N/kg di N lisciviato o dilavato/kg N applicato
EF1	0.01	Triangle		0.001	0.018	<input type="checkbox"/>	kg N <sub>2</sub> O-N/kg N applicato
Seed	130	Triangle		120	140	<input type="checkbox"/>	Densità di semina kg semi/ha]
DISTCA	2.5	Triangle		1	4	<input type="checkbox"/>	Distanza campo-ammassatore [km]
Add							

Calculated parameters	Expression	Comment
Crop	$CropYield * SSCrop * 1000 = 1.5E3$	SS nella granella raccolta [kg/ha]
AG	$(Crop/1000 * 1.13 + .85) * 1000 = 2.55E3$	Sostanza secca nella biomassa sup [kg/h]
RBG	$RBGBIO * (AG + Crop) / Crop = 0.512$	Rapporto fra la SS nei residui radicali/SS nella biomassa raccolta g/g]
BG	$RBG * Crop = 770$	SS nei residui sotterranei [kg/ha]
FCR	$FRACrenew * ((A - Aburnt * Cf) * AG * NAG * (1 - FRACremoved) + A * BG * NBG) = 26.6$	N nei residui sup e sott restituiti al suolo [kg/ha]
NPKU	$NPK * 20 / 15 = 133$	Fertilizzante NPK (15-15-15) [kg/ha]
FSN	$0.15 * NPKU = 20$	N sintetico [kg/ha]
FON	$0.04 * PM = 8$	N organico [kg/ha]
FNH3NOX	$FSN * FRACgasf + (FON + FPRP) * FRACgasm = 3.88$	kg NH <sub>3</sub> e NOX volatilizzato/ha
FNO3	$(FSN + FON + FPRP + FCR + FSOM) * FRACleach = 13.1$	kg N lisciviato o dilavato/ha
FN2OD	$44 / 28 * A * (FSN + FON + FCR + FSOM) * EF1 = 0.857$	kg N <sub>2</sub> O-N dirette
FN2OIND	$44 / 28 * A * (FNH3NOX * EF4 + FNO3 * EF5) = 0.287$	kg N <sub>2</sub> O-N indirette
FN2O	$FN2OD + FN2OIND = 1.14$	kg N <sub>2</sub> O-N totali
NOAN	$0.5 * NPK / (2 * 14 + 4 + 3 * 16) * (2 * 14) = 17.5$	kg N/ha se 50% NPK = AN (NH <sub>4</sub> NO <sub>3</sub> )
NOCAN	$0.5 * NPK * (4 * 14) / (40 + 4 + 4 * 14 + 9 * 16) = 11.5$	kg N/ha se 50% NPK = CAN (Ca NH <sub>4</sub> (NO <sub>3</sub> ) <sub>3</sub> )
NO	$NOAN * 0.029 + NOCAN * 0.016 + FON * 0.005 = 0.731$	EPD (2020) Emissioni NO [kg/ha]
PLEACH	$(NPKU * .15 + PM * .04) * (2 * 31) / (2 * 31 + 5 * 16) * .05 = 0.611$	P lisciviato= 0.05 P sint ed organico [kg/ha]

**Table S1.3**

Inventory associated with the production of Aluminum phosphide (AIP) tablets.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC - 3 AIP		ALPTABLET = 1	kg	Mass	100 %	Aluminium	Chemicals			
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs from technosphere: materials/fuels		Amount			Unit	Distrik	SD2 c	Min	Max	Comment
Aluminium, primary, liquid (GLO)   market for aluminium, primary, liquid   Cut-off, S		ALPTABLET*0.46552*xAIP = 0.261			kg					
Phosphorus, white, liquid (GLO)   market for phosphorus, white, liquid   Cut-off, S		ALPTABLET*0.53448*xAIP = 0.299			kg					
Aluminium oxide, non-metallurgical (IAI Area, Russia & RER w/o EU27 & EFTA)   aluminium ox		ALPTABLET*(xAIO+xAIS) = 0.17			kg					
Graphite (GLO)   market for graphite   Cut-off, S		ALPTABLET*xG = 0.015			kg					
Urea (RER)   urea production   Cut-off, S		ALPTABLET*xU = 0.18			kg					
Ammonium carbonate (RER)   market for ammonium carbonate   Cut-off, S		ALPTABLET*xAMC = 0.05			kg					
Paraffin (GLO)   market for paraffin   Cut-off, S		ALPTABLET*xPW = 0.025			kg					
Inputs from technosphere: electricity/heat		Amount			Unit	Dis	S	Comment		
Heat, district or industrial, natural gas (Europe without Switzerland)   market for heat, district or industrial, natural gas   Cut-off, S		ALPTABLET*xAIP*(0.46552*En			kJ					
Dolomite grinding (GLO)   dolomite grinding   production mix, at plant   2.90 g/cm3   Partly terminated system		ALPTABLET*xAIP = 0.56			kg				Grinding of P and Al	
Transport, freight, lorry 3.5-7.5 metric ton, EURO5 (RER)   transport, freight, lorry 3.5-7.5 metric ton, EURO5   Cut-off, S		ALPTABLET/1000*300 = 0.3			tkm				TR: MP - Fondi: 200 km	
Transport, freight, light commercial vehicle (Europe without Switzerland)   transport, freight, light commercial vehicle   Cut-off, S		ALPTABLET/1000*280 = 0.28			tkm				TR: Fondi-AP: 280 km	

Documentation	Input/output	Parameters	System description
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Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
xAIP	0.56	Undefined				<input type="checkbox"/>	Frazione di AIP nelle tablets
xAMC	0.05	Undefined				<input type="checkbox"/>	Frazione di ammonium carbonate (w/w)
xAIS	0.025	Undefined				<input type="checkbox"/>	Frazione di aluminium stearate (w/w)
xAIO	0.145	Undefined				<input type="checkbox"/>	Frazione di aluminium oxide/hydroxide (w/w)
xU	0.18	Undefined				<input type="checkbox"/>	Frazione di urea (w/w)
xG	0.015	Undefined				<input type="checkbox"/>	Frazione di graphite (w/w)
xPW	0.025	Undefined				<input type="checkbox"/>	Frazione di paraffin wax (w/w)
ALPABLET	1	Undefined				<input type="checkbox"/>	Massa di una compressa [g]
CpPS	0.77	Undefined				<input type="checkbox"/>	Specifi heat value of solid P {kJ/(kg K)}: <a href="https://www.periodic-table.org/phosphorus-latent-heat-vaporization/">https://www.periodic-table.org/phosphorus-latent-heat-vaporization/</a>
CpPL	0.85	Undefined				<input type="checkbox"/>	Specific heat value of liquid P {kJ/(kg K)}: <a href="https://webbook.nist.gov/cgi/inchi?ID=C7723140&amp;Mask=2">https://webbook.nist.gov/cgi/inchi?ID=C7723140&amp;Mask=2</a>
CpPV	0.5	Undefined				<input type="checkbox"/>	Specific heat value of vapor P {kJ/(kg K)}
DELTAHfusP	0.657	Undefined				<input type="checkbox"/>	[kJ/mol]
DELTAHvapP	51.9	Undefined				<input type="checkbox"/>	[kJ/mol]
CpAIS	0.9	Undefined				<input type="checkbox"/>	Specifi heat value of solid Al {kJ/(kg K)}
CpAIL	1.127	Undefined				<input type="checkbox"/>	Specifi heat value of liquid Al {kJ/(kg K)}
DELTAHfusAl	10.79	Undefined				<input type="checkbox"/>	[kJ/mol]
TfusP	44.1	Undefined				<input type="checkbox"/>	Temperatura di fusione P [°C]
TBP	280	Undefined				<input type="checkbox"/>	Temperatura di ebollizione P °C
TfusAL	660	Undefined				<input type="checkbox"/>	Temperatura di fusione Al [°C]
TR	700	Undefined				<input type="checkbox"/>	Temperatura di reazione °C]

Calculated parameters	Expression	Comment
EntP	$CpPS*(TfusP-20)+DELTAHfusP/0.031+CpPL*(TBP-TfusP)+DELTAHvapP/.031+CpPV*(TR-TBP) = 2.1$	Calore di riscald P [kJ/kg]
EntAl	$CpAIS*(TfusAL-20)+DELTAHfusAl/0.027+CpAIL*(TR-TfusAL) = 1.02E3$	Calore di riscald Al [kJ/kg]

**Table S1.4**

Inventory associated with the pulse grain fumigation step.

Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 4 Fumigated grains			17100.171	kg	Mass	100 %	Biopolymers	Agr...\Plant seeds	
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment
SDC- 1 grains			17100	kg	Unde				
SDC - 3 AIP			0.2565	kg	Unde				
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment
Outputs									
Emissions to air		Sub-compartment	Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment
Phosphine			85.5	g	Unde				
Documentation	Input/output	Parameters		System description					
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment		
SCPUL	12.5	Triangle		10	15	<input type="checkbox"/>	Scarto di pulitura [%]		
DUST	2	Triangle		1.6	2.4	<input type="checkbox"/>	Polvere [%]		
GI	6	Triangle		4.8	7.2	<input type="checkbox"/>	Grass & Insects [%]		
WASTE	4.5	Triangle		3.6	5.4	<input type="checkbox"/>	Legumi spezzati etc [%]		
Calculated parameters		Expression				Comment			

**Table S1.5**

Inventory associated with the production of 1-Mg PE bags.

Products									
Outputs to technosphere: Products and co-products	Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC - 2 PE Supersacks	3	kg	Mass	100 %	LDPE	P..\Thermoplasts			
Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Inputs									
Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs from technosphere: materials/fuels	Amount			Unit	Distrib	SD2	Min	Max	Comment
Packaging film, low density polyethylene (RER)   packaging film production, low density polye	3/0.976 = 3.07			kg					Resa di conversione in film: 0.976 kg/kg F
Inputs from technosphere: electricity/heat	Amount			Unit	Dis	S	Comment		
Extrusion, plastic film (RER)   extrusion, plastic film   Cut-off, S	3/.976 = 3.07			kg			0.976 kg		
Transport, freight, light commercial vehicle (Europe without Switzerland)   transport, freight, light commercial vehicle   Cut-off, S	3/1000*355 = 1.06			tkm			Distanza SS - Azienda conf: 355 km		
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)   transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S	(3/.976)/1000*300 = 0.922			tkm			Distanza Fornitore PE - Azienda RE: 300 km		
Outputs to technosphere: Waste and emissions to treatment	Amount					Unit	Distri		
Waste polyethylene (Europe without Switzerland)   market group for waste polyethylene   Cut-off, S	3*(1-0.976) = 0.072					kg			

**Table S1.6**

Inventory associated with the flexible intermediate bulk container (FIBC)-packed cleaned dry pulse grain production step.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC - 5 FIBC-packed cleaned dry pulse grains		GPP = 1.5E4	kg	Mass	99.6 %	Biopolymers	Agr...\Plant seeds	Legumi puliti nei supersacch		
SDC - waste		2137.7	kg	Mass	0.4 %	Biopolymers	Agr...\Plant seeds			
Add										
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels		Amount			Unit	Distrit	SD2 <	Min	Max	Comment
SDC - 4 Fumigated grains		17100.171			kg	Unde:				
SDC - 2 PE Supersacks		44.9			kg	Unde:				
Add										
Inputs from technosphere: electricity/heat		Amount			Unit	Dis S	Comment			
Add										

**Table S1.7**

Inventory associated with the production of ready-to-pack dried pulses.

Documentation	Input/output	Parameters	System description						
Input parameters		Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment	
	GP	14962.5	Undefined				<input type="checkbox"/>	Cleaned pulses grains [kg]	
	SS	44.9	Undefined				<input type="checkbox"/>	PE-sacks [kg]	
		Add							
Calculated parameters		Expression						Comment	
	GPP	GP+SS = 1.5E4						PE-bagged cleaned pulse grains [kg]	
		Add							
Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 6 ready-to-pack dry grains			GPD = 1.31E4	kg	Mass	100 %	Biopolymers	Agr...\Plant seeds	Legumi puliti nei supersacch
SDC - DGI			GRF*(DUST+GI) = 1.37E3	kg	Mass	0 %	Others	Others	Dust, grass & Insect waste
SDC - MZ			GRF*BP+0.005*GPD = 835	kg	Mass	0 %	Biopolymers	Ag...\Bovine feed	Pulse Waste used as cattle fe
SDC - seeds			Seed*A = 1.3E3	kg	Mass	0 %	Biopolymers	Agr...\Plant seeds	Seeds used
			Add						
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
			Add						
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
		Add							
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment
SDC - 5 FIBC-packed cleaned dry pulse grains			GPP = 1.5E4	kg					
			Add						
Inputs from technosphere: electricity/heat			Amount	Unit	Dis	S	Comment		
Transport, tractor and trailer, agricultural (RoW)   transport, tractor and trailer, agricultural   Cut-off, S			GRF*(DUST+GI)/1000*4 = 5.4	tkm					TR: AP- field: 4 km
Transport, tractor and trailer, agricultural (RoW)   transport, tractor and trailer, agricultural   Cut-off, S			(GRF*BP+0.005*GPD)/1000*(1	tkm					TR: AP - Beef cattle farms: 50 km
Outputs to technosphere: Waste and emissions to treatment			Amount	Unit	Distri				
Waste polyethylene (RoW)   treatment of waste polyethylene, municipal incineration   Cut-off, S			SS*0.446 = 20	kg					
Waste polyethylene (RoW)   treatment of waste polyethylene, sanitary landfill   Cut-off, S			SS*0.067 = 3.01	kg					
PE (waste treatment) (GLO)   recycling of PE   Cut-off, S			SS*0.487 = 21.9	kg					

**Table S1.8**

Inventory associated with the PP bag production step.

Products									
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC- 7 PP bags		1	kg	Mass	100 %	PP	P...\Thermoplasts		
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs									
Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs from technosphere: materials/fuels		Amount	Unit	Distrit	SD2 c	Min	Max	Comment	
Polypropylene, granulate (GLO)  market for polypropylene, granulate   Cut-off, S		1/976 = 1.02	kg					Resa: 0.976 kg /kg PP	
Inputs from technosphere: electricity/heat		Amount	Unit	Dis	S	Comment			
Extrusion, plastic film (RER)  extrusion, plastic film   Cut-off, S		1/976 = 1.02	kg						
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)  transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S		(1/976)/1000*300 = 0.307	tkm			TR PP Granules Prod Site - Pl: 300 km			
Outputs to technosphere: Waste and emissions to treatment		Amount	Unit	Distri					
Waste polypropylene (Europe without Switzerland)  market group for waste polypropylene   Cut-off, S		0.024	kg	Unde					

**Table S1.9**

Inventory associated with the cardboard collar production step.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC - 8 Cardstock		1	kg	Mass	100 %	not defined	Agr...\Plant seeds			
Add										
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels		Amount		Unit	Distrit	SD2 or 2SD	Min	Max	Comment	
Kraft paper (RER)  market for kraft paper   Cut-off, S		1		kg	Unde					
Add										
Inputs from technosphere: electricity/heat		Amount		Unit	Dis	S	Comment			
Printed paper, offset (RoW)  offset printing, per kg printed paper   Cut-off, S		1		kg	Un					
Transport, freight, lorry >32 metric ton, EURO5 (RER)  transport, freight, lorry >32 metric ton, EURO5   Cut-off, S		(1/1000)*300 = 0.3		tkm			TR Cartoncino PS-Montefiascone: 300 km			

**Table S1.10**

Inventory associated with the brass rivet production step.

Products									
Outputs to technosphere: Products and co-products		Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment	
SDC - 9 - Brass rivets		1	kg	Mass	100 %	Non-ferro	Metals\Non Ferrc		
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs from technosphere: materials/fuels		Amount		Unit	Distrib	SD2	Min	Max	Comment
Brass (RoW)  market for brass   Cut-off, S		1		kg	Unde				
Inputs from technosphere: electricity/heat		Amount		Unit	Dis	S	Comment		
Brass Die-Casting (GLO)   die casting, from copper and zinc, primary production   production mix, at plant   8.41- 8.86 g/cm3   Pa		1		kg	Un				
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)  transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S		(1/1000)*300 = 0.3		tkm					TR Ottone: PS- Pl: 300 km

**Table S1.11**

Inventory associated with the adhesive paper label production step.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment		
SDC - 10 Adhesive paper labels		1	kg	Mass	100 %	Paper	...\Graphic paper			
Add										
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Graphic paper, 100% recycled (GLO)   market for graphic paper, 100% recycled   Cut-off, S		1	kg	Under						
Add										
Inputs from technosphere: electricity/heat		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)   market for transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S		$(1/1000)*300 = 0.3$	tkm					TR Paper x Labels: PS -Montefiascone: 300 km		
Acrylic binder, with water, in 54% solution state (RER)   market for acrylic binder, with water, in 54% solution state   Cut-off, S		$5*1210/(5*1210+600*1000) =$	kg							

**Table S1.12**

Inventory associated with the carton production step (copied from Carton box {EU+EFTA+UK} | Kraft Pulping Process, pulp pressing and drying, box manufacturing | production mix, at plant | 280 g/m<sup>2</sup>, R1=47% | LCI result, EF database 3.1 Corepackage – Sphera).

Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 11 Carton box			1.0	kg	Mass	100 %	Cardboard	Pap...\Packaging	Product flow name: Carton k
Add									
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add									
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Air		in air	5.1649277E1	kg	Undefined				
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)  transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S					(1/1000)*300 = 0.3	tkm			TR PS-PG: 300 km

**Table S1.13**

Inventory associated with the scotch tape production step.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC- 12 Scotch		1	kg	Mass	100 %	PP	P...\Thermoplasts			
Add										
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels		Amount			Unit	Distrib	SD2 c	Min	Max	Comment
Polypropylene, granulate (GLO)   market for polypropylene, granulate   Cut-off, S		(1-0.0425)/.976 = 0.981			kg					Resa: 0.976 kg /kg PP
Add										
Inputs from technosphere: electricity/heat		Amount			Unit	Dis	S	Comment		
Extrusion, plastic film (RER)   extrusion, plastic film   Cut-off, S		(1-0.0425)/.976 = 0.981			kg					
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER)   transport, freight, lorry 7.5-16 metric ton, EURO5   Cut-off, S		((1-0.0425)/.976+0.0425)/100			tkm					TR PP Granules Prod Site - PI: 300 km
Acrylic binder, with water, in 54% solution state (RER)   market for acrylic binder, with water, in 54% solution state   Cut-off, S		10*1210/(10*1210+300*950) :			kg					tape thickness 300 micron (950 kg/m3), acrylic layer 10 micron (1210 kg/m3)
Outputs to technosphere: Waste and emissions to treatment		Amount			Unit	Distri				
Waste polypropylene (Europe without Switzerland)   market group for waste polypropylene   Cut-off, S		0.024			kg	Unde				

**Table S1.14**

Inventory associated with the PP semi-pallet production step.

Products										
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC - 13 semipallet			1	kg	Mass	100 %	PP	P...\Thermoplasts		
Add										
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels			Amount	Unit	Distrik	SD2 c	Min	Max	Comment	
Polypropylene, recycled, pre-consumer (GLO)   shredding, pelletizing   production mix, at plan			1/.98 = 1.02	kg					Resa: 0.98 kg /kg PP	
Add										
Inputs from technosphere: electricity/heat			Amount	Unit	Dis	S	Comment			
Injection moulding (RER)   injection moulding   Cut-off, S			1/.98 = 1.02	kg						
Transport, freight, lorry 16-32 metric ton, EURO5 (RoW)   transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S			(1/.98)/1000*300 = 0.306	tkm			TR PP Granules Prod Site - Pl: 300 km			
Outputs to technosphere: Waste and emissions to treatment			Amount	Unit	Distri					
Waste polypropylene (Europe without Switzerland)   market group for waste polypropylene   Cut-off, S			0.02	kg	Unde					

**Table S1.15**

Inventory associated with the shrink & shrank PE film production step.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC- 14 PE shrinkable film		1	kg	Mass	100 %	PE	P...\Thermoplasts			
Add										
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels		Amount		Unit	Distrik	SD2	κ	Min	Max	Comment
Polyethylene, low density, granulate (RER)   polyethylene production, low density, granulate   C		1/.976 = 1.02		kg						Resa: 0.976 kg /kg PP
Add										
Inputs from technosphere: electricity/heat		Amount		Unit	Dis	S	Comment			
Extrusion, plastic film (RER)   extrusion, plastic film   Cut-off, S		1/.976 = 1.02		kg						
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)   transport, freight, lorry 16-32 metric ton, EURO5   Cut-off, S		(1/.976)/1000*300 = 0.307		tkm			TR PP Granules Prod Site - Pl: 300 km			
Outputs to technosphere: Waste and emissions to treatment		Amount		Unit	Distri					
Waste polyethylene (ES)   market for waste polyethylene   Cut-off, S		0.024		kg	Unde					

**Table S1.16**

Assembly of the primary packaging for dried pulses.

Input/output	Parameters											
Name	Status	Comment										
SDC - 15 Assembly of Primary Packaging	None											
Materials/Assemblies	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment					
SDC - 7 PP bags	PPBAG = 5	g										
SDC - 8 Cardstock	CAV = 5.8	g										
SDC - 9 - Brass rivets	2*RIV = 0.66	g										
SDC - 10 Adhesive paper labels	ET = 0.323	g										
Add												
Processes						Amount	Unit	D	SD	N	M	Comment
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER)   market for transport, freight, lorry 7.5-16 metric ton, EURO5   Cut-off, S						(PPBAG+2*RIV)/1000*200 = 1.13	kgkm					TR: PI-AP: 200 km
Transport, freight, light commercial vehicle (Europe without Switzerland)   market for transport, freight, light commercial vehicle   Cut-off, S						(CAV+ET)/1000*30 = 0.184	kgkm					TR: Montefiascone-AP: 30 km
Input/output	Parameters											
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment					
PPBAG	5	Normal	0.3			<input type="checkbox"/>						
CAV	5.8	Normal	0.6			<input type="checkbox"/>						
RIV	0.33	Normal	0.03			<input type="checkbox"/>						
ET	0.323	Normal	0.03			<input type="checkbox"/>						

**Table S1.17**

Assembly of the secondary packaging for dried pulses.

Input/output		Parameters					
Name		Status		Comment			
SDC - 16 Assembly of Secondary Packaging		None					
Materials/Assemblies	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 11 Carton box	CA = 302	g					
SDC - 10 Adhesive paper labels	EC = 2	g					
SDC - 12 Scotch	SC = 4	g					
Add							
Processes					Amount	Unit	D SD: N M Comment
Transport, freight, light commercial vehicle (Europe without Switzerland)   market for transport, freight, light commercial vehicle   Cut-off, S					EC/1000*30 = 0.06	kgkm	TR: Montefiascone - AP: 30 km
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER)   market for transport, freight, lorry 7.5-16 metric ton, EURO5   Cut-off, S					(CA*105+SC*200)/1000 = 32.5	kgkm	TR: PG o PI - AP: 105 o 200 km
Input/output		Parameters					
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
CA	302	Normal	3			<input type="checkbox"/>	g
EC	2.0	Normal	0.2			<input type="checkbox"/>	g
SC	4	Normal	0.4			<input type="checkbox"/>	g
Add							

**Table S1.18**

Assembly of the tertiary packaging for dried pulses.

Input/output		Parameters						
Name		Status		Comment				
SDC - 17 Assembly of Tertiary Packaging		None						
Materials/Assemblies		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 13 semipallet		PAL = 5	kg					
		Add						
Processes		Amount		Unit	D	N	M	Comment
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER)  market for transport, freight, lorry 7.5-16 metric ton, EURO5   Cut-off, S		(PAL*0.02)*200 = 20		kgkm				TR: PI - AP: 200 km (solo frazione da reintragnare: 0.02%)
Input/output		Parameters						
Input parameters		Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
PAL		5	Normal	0.1			<input type="checkbox"/>	kg
		Add						

**Table S1.19**

Assembly of primary and secondary packages for dried pulses.

Input/output		Parameters					
Name		Status		Comment			
SDC - 18 Assembly of I-II packages		None					
Materials/Assemblies	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 15 Assembly of Primary Packaging	12	p	Undefined				
SDC - 16 Assembly of Secondary Packaging	1	p	Undefined				
Add							
Processes					Amount	Unit	D N M Comment
Add							

**Table S1.20**

Assembly of primary, secondary, and tertiary packages for dried pulses.

Input/output	Parameters										
Name	Status	Comment									
SDC - 19 Assembly of I-II-III packages	None										
Materials/Assemblies	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment				
SDC - 18 Assembly of I-II packages	24	p	Undefined								
SDC- 14 PE shrinkable film	FP = 287	g									
SDC - 10 Adhesive paper labels	EP*2 = 6.22	g									
SDC - 17 Assembly of Tertiary Packaging	1	p	Undefined								
Add											
Processes						Amount	Unit	D	N	M	Comment
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER)  market for transport, freight, lorry 7.5-16 metric ton, EURO5   Cut-off, S						(FP/1000)*200 = 57.4	kgkm				TR: PI - AP: 200 km
Transport, freight, light commercial vehicle (Europe without Switzerland)  market for transport, freight, light commercial vehicle   C						(EP*2/1000)*30 = 0.187	kgkm				TR: Montefiascone - AP: 30 km
Input/output	Parameters										
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment				
EP	3.11	Normal	0.3			<input type="checkbox"/>	g				
FP	287	Normal	20			<input type="checkbox"/>	g				

**Table S1.21**

Assembly of dried pulses (1 Functional Unit).

Input/output	Parameters	
Name	Status	Comment
SDC - 20 Assembly of Dry Grains	None	
Materials/Assemblies	Amount	Unit
SDC - 5 FIBC-packed cleaned dry pulse grains	MDP = 0.5	kg
Nitrogen gas production (EU+EFTA+UK)   technology mix   production mix, at plant   100% active substance   LCI result	N2 = 5	g
Add		
Processes	Amount	Unit
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER)   market for transport, freight, lorry 7.5-16 metric ton, EURO5   Cut-off, S	N2/1000*35 = 0.175	kgkm
Electricity, medium voltage (IT)   market for electricity, medium voltage   Cut-off, S	EECONS*MDP = 0.33	kWh
Input/output	Parameters	
Input parameters	Value	Distribution
MDP	0.5	Undefined
N2	5	Normal
EECONS	0.66	Undefined

**Table S1.22**

Inventory associated with the use phase.

Products									
Outputs to technosphere: Products and co-products	Amount	Unit	Quantit	Allocation %	Category	Comment			
SDC - 21 Use phase	RDP = 1	kg	Mass	100 %	Others				
SDC - Cooked pulses wasted	MPC*CPWASTED = 0.262	kg	Mass	0 %	Others				
Add									
Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add									
Inputs									
Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add									
Inputs from technosphere: materials/fuels	Amount	Unit	Distrib	SD2 c	Min	Max	Comment		
Tap water {Europe without Switzerland} market for tap water   Cut-off, S	(WAM+WAC)*RDP+CONSW*NCL = 15.8	kg						Acqua per amm+ cott + acqua x lavastov	
Detergent dish production {EU+EFTA+UK}   production mix   1 kg of detergent dish   LCI resul	CONSDet*NCL = 7.14	g						Detersivo consumato x lavastoviglie	
Add									
Inputs from technosphere: electricity/heat	Amount	Unit	Dis	S	Comment				
Heat, central or small-scale, natural gas {Europe without Switzerland} market for heat, central or small-scale, natural gas   Cut-off	ECG*RDP = 1.41	kWh			Consumo Gas nat fornelli a gas				
Electricity, low voltage {IT} market for electricity, low voltage   Cut-off, S	ECE*RDP+CONSEE*NCL = 0.8	kWh			Consumo EE (fornello+lavastoviglie)				
Municipal waste collection service by 21 metric ton lorry {GLO} market for municipal waste collection service by 21 metric ton lorry	MPC*CPWASTED*50 = 13.1	kgkm			TR: House-MSWCS: 50 km				
Outputs									
Emissions to air	Sub-compartment	Amount	Unit	Distrib	SD2 or	Min	Max	Comment	
Water (evapotranspiration)	low. pop.	WAC*RDP*W <sub>evap</sub> = 0.2	kg						
Nitrogen, total	low. pop.	10*RDP = 10	g						
Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distrib						
Sludge from pulp and paper production {Europe without Switzerland} treatment of sludge from pulp and paper production, sanitary landfill   Cut-off, S	MPC*CPWASTED*.31 = 0.0812	kg							
Raw sewage sludge {RoW} treatment of raw sewage sludge, municipal incineration   Cut-off, S	MPC*CPWASTED*.18 = 0.0472	kg							
Biowaste {RoW} treatment of biowaste by anaerobic digestion   Cut-off, S	MPC*CPWASTED*.255 = 0.0668	kg							
Biowaste {RoW} treatment of biowaste, industrial composting   Cut-off, S	MPC*CPWASTED*.255 = 0.0668	kg							
Wastewater, average {Europe without Switzerland} market for wastewater, average   Cut-off, S	(WASTEWAM+WASTEWC)*RDP+CONSW*NCL = 14	l							

Documentation	Input/output	Parameters	System description				
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
RDP	1	Undefined				<input type="checkbox"/>	Dry pulses [kg]
XMDP	0.083	Undefined				<input type="checkbox"/>	Umidità iniziale legumi [g/g]
WAM	4	Undefined				<input type="checkbox"/>	Acqua x ammollo [L/kg dried pulses]
XMAM	0.55	Triangle		0.5	0.6	<input type="checkbox"/>	Umidità legumi post-ammollo [g/g]
WAC	4	Undefined				<input type="checkbox"/>	Acqua x cottura [L/kg dried pulses]
XMC	0.65	Triangle		0.62	0.68	<input type="checkbox"/>	Umidità legumi post-cottura [g/g]
GCH	0.83	Undefined				<input type="checkbox"/>	Frazione dei fornelli a gas
ECH	0.17	Undefined				<input type="checkbox"/>	Frazione dei fornelli elettrici
ETC	1.7	Undefined				<input type="checkbox"/>	Energia totale di cottura [kWh/kg]
CPWASTED	0.1	Triangle		0.08	0.12	<input type="checkbox"/>	Frazione legumi cotti sprecati [g/g]
Portion	50	Undefined				<input type="checkbox"/>	Porzione consumata di legumi secchi [g]
NCOP	28	Undefined				<input type="checkbox"/>	No coperti/ciclo di lavaggio
CONSEE	0.74	Undefined				<input type="checkbox"/>	Cons EE [kWh/ciclo di lavaggio]
CONSW	10.9	Undefined				<input type="checkbox"/>	Cons acqua [L/ciclo di lavaggio]
CONSDET	10	Undefined				<input type="checkbox"/>	Cons detersivo [g/ciclo di lavaggio]
Wevap	0.05	Undefined				<input type="checkbox"/>	Frazione acqua di cottura evaporata [g/g]
Add							

Calculated parameters	Expression	Comment
MPI	$RDP \cdot (1 - XMDP) / (1 - XMAM) = 2.04$	Massa legumi post-ammollo [kg]
WASTEWAM	$WAM \cdot RDP - (MPI \cdot XMAM - RDP \cdot XMDP) = 2.96$	Acqua da smaltire post-ammollo [kg]
MPC	$RDP \cdot (1 - XMDP) / (1 - XMC) = 2.62$	Massa legumi post-cottura [kg]
WASTEWC	$WAC \cdot RDP - (MPC \cdot XMC - MPI \cdot XMAM) - Wevap \cdot WAC = 3.22$	Acqua da smaltire post-cottura [kg]
ECG	$GCH \cdot ETC \cdot RDP = 1.41$	Energia termica consumata per cuocere RDP kWh
ECE	$ECH \cdot ETC \cdot RDP = 0.289$	Energia elettrica consumata per cuocere RDP kWh
NSCOD	$RDP \cdot 1000 / Portion = 20$	No. scodelle utilizzate
NCL	$NSCOD / NCOP = 0.714$	No. cicli di lavaggio in lavastoviglie per consumare RDP

**Table S1.23**

Waste scenario for plastic packaging wastes (PLW).

Products				
----------	--	--	--	--

Waste specification	Amount	Unit	Category	Comment
SDC -22 Waste scenario plastic wastes	1	kg	Others	

Inputs						
--------	--	--	--	--	--	--

Inputs from technosphere: materials/fuels	Amount	Unit	Distrib	SD2	Min	Max	Comment
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Dis	S	Comment
Add					

Outputs			
---------	--	--	--

Materials and/or waste types separated from waste stream	Material / Waste type	Percentage	Comment
Add			

Waste streams remaining after separation	Percentage	Comment
Waste plastic, mixture (RoW)   treatment of waste plastic, mixture, sanitary landfill   Cut-off, S	6.7 %	
Mixed plastics (waste treatment) (GLO)   recycling of mixed plastics   Cut-off, S	48.7 %	
Waste plastic, mixture (RoW)   treatment of waste plastic, mixture, municipal incineration   Cut-off, S	44.6 %	

**Table S1.24**

Waste scenario for cardboard and paper packaging wastes (PCW).

Products								
Waste specification	Amount	Unit	Category	Comment				
SDC -23 Waste scenario Cardboard&paper packagi	1	kg	Others					
Inputs								
Inputs from technosphere: materials/fuels	Amount		Unit	Distrib	SD2 c	Min	Max	Comment
Inputs from technosphere: electricity/heat	Amount		Unit	Dis	S	Comment		
Outputs								
Materials and/or waste types separated from waste stream	Material / Waste type			Percentage	Comment			
Waste streams remaining after separation				Percentage	Comment			
Waste paperboard (RoW)  treatment of waste paperboard, sanitary landfill   Cut-off, S				5.2 %				
Paper (waste treatment) (GLO)  recycling of paper   Cut-off, S				87.3 %				
Waste paperboard (RoW)  treatment of waste paperboard, municipal incineration   Cut-off, S				7.5 %				

**Table S1.25**

Waste scenario of non-ferrous metal waste (NFMW).

Products							
Waste specification	Amount	Unit	Category	Comment			
SDC -24 Waste scenario non-ferrous metal wastes	1	kg	Others				
Inputs							
Inputs from technosphere: materials/fuels	Amount	Unit	Distrit	SD2 c	Min	Max	Comment
Inputs from technosphere: electricity/heat	Amount	Unit	Dis	S	Comment		
Outputs							
Materials and/or waste types separated from waste stream	Material / Waste type	Percentage	Comment				
Waste streams remaining after separation		Percentage	Comment				
Waste aluminium (RoW)  treatment of waste aluminium, sanitary landfill   Cut-off, S		25.4 %					
Aluminium (waste treatment) (GLO)  recycling of aluminium   Cut-off, S		68.1 %					
Scrap copper (Europe without Switzerland)  treatment of scrap copper, municipal incineration   Cut-off, S		6.5 %					

**Table S1.26**

Disposal scenario of primary packaging material wastes (DS-1pack).

Name	Status	Comment				
SDC - 25 Disposal Scenario of Primary Packaging	None					
Referring to assembly	Amount	Unit	Comment			
SDC - 15 Assembly of Primary Packaging	1	p				
Processes	Amount	Unit	D	M	N	Comment
Municipal waste collection service by 21 metric ton lorry (GLO) market for municipal waste collection service by 21 metric ton lorry	$(11.941/1000)*50 = 0.597$	kgkm				TR - Wastes to MSWCS: 50 km
Waste scenarios	Percentage	Comment				
SDC -23 Waste scenario Cardboard&paper packaging	55.3 %					
SDC -24 Waste scenario non-ferrous metal wastes	2.8 %					
SDC -22 Waste scenario plastic wastes	41.9 %					
Disassemblies	Percentage	Comment				
Reuses	Percentage	Comment				

**Table S1.27**

Disposal scenario of secondary packaging material wastes (DS-2pack).

Name	Status	Comment				
SDC - 26 Disposal Scenario of Secondary Packaging	None					
Referring to assembly	Amount	Unit	Comment			
SDC - 16 Assembly of Secondary Packaging	1	p				
Processes	Amount	Unit	D	M	M	Comment
Municipal waste collection service by 21 metric ton lorry {GLO} market for municipal waste collection service by 21 metric ton lorry	$(308/1000)*50 = 15.4$	kgkm				TR - Wastes to MSWCS: 50 km
Waste scenarios	Percentage	Comment				
SDC -23 Waste scenario Cardboard&paper packaging	98.7 %					
SDC -22 Waste scenario plastic wastes	1.3 %					
Disassemblies	Percentage	Comment				
Reuses	Percentage	Comment				

**Table S1.28**

Disposal scenario of tertiary packaging material wastes (DS-3pack).

Name	Status	Comment
SDC - 27 Disposal Scenario of Tertiary Packaging	None	

Referring to assembly	Amount	Unit	Comment
SDC - 17 Assembly of Tertiary Packaging	1	p	

Processes	Amount	Unit	D	M	V	Comment
Municipal waste collection service by 21 metric ton lorry (GLO} market for municipal waste collection service by 21 metric ton lorry	$(PAL * .02 / 1000) * 50 = 0.00$	tkm				TR - Wastes to MSWCS: 50 km
Add						

Waste scenarios	Percentage	Comment
SDC - 22 Waste scenario plastic wastes	0.2 %	
Add		

Disassemblies	Percentage	Comment
Add		

Reuses	Percentage	Comment
SDC - 29 Semipallet reuse	99.8 %	
Add		

**Table S1.29**

Disposal scenario of the primary, secondary and tertiary packaging material wastes (DS-1-3pack).

Name	Status	Comment			
SDC - 28 Disposal Scenario of I-II-III Packaging	None				
Referring to assembly	Amount	Unit	Comment		
SDC - 19 Assembly of I-II-III packages	1	p			
Processes	Amount	Unit	D	M	Comment
Municipal waste collection service by 21 metric ton lorry (GLO)  market for municipal waste collection service by 21 metric ton lorry   Cut-off, S	(0.294)*50 = 14.7	kgkm			TR - Paper & Plastic Wastes in a pallet to MSWCS: 5
Waste scenarios	Percentage	Comment			
SDC -22 Waste scenario plastic wastes	19.845 %				
SDC -23 Waste scenario Cardboard&paper packaging	79.331 %				
SDC -24 Waste scenario non-ferrous metal wastes	0.824 %				
Disassemblies	Percentage	Comment			
Reuses	Percentage	Comment			

**Table S1.30**

Reuse phase of the PP semi-pallet.

Input/output		Parameters					
Name		Status		Comment			
SDC - 29 Semipallet reuse		None					
Referring to assembly		Amount	Unit	Comment			
SDC - 17 Assembly of Tertiary Packaging		1	p				
Processes		Amount	Unit	D	M	Comment	
Transport, freight, light commercial vehicle (Europe without Switzerland)   market for transport, freight, light commercial vehicle   Cut-off, S		(PAL*.998)/1000*1	tkm			TR: Sale Points - AP: 150 km	
Input/output		Parameters					
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
PAL	5	Normal	0.5			<input type="checkbox"/>	Mass of semipallet PE [kg]

**Table S1.31**

Life cycle of dried pulses (LC-DP).

Input/output		Parameters						
Name		Status		Comment				
SDC - 30 Life cycle of Dried Pulses		None						
Assembly		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 20 Assembly of Dry Grains		2	p	Undefined				Two 500-g bags
Processes		Amount		Unit	Dis	N	Comment	
Transport, freight, light commercial vehicle [Europe without Switzerland] market for transport, freight, light commercial vehicle   Cut-off, S		(PPDP/MDP*1)*150 = 168		kgkm			TR - Dried Pulses - Points of Sale: 150 km	
SDC - 21 Use phase		1		kg	Ur			
Waste/Disposal scenario		Comment						
Additional life cycles		Number	Distribution	SD2 or 2SD	Min	Max	Comment	
SDC - 31 Life Cycle of I-II-III packaging		1/144 = 0.00694						
Input/output		Parameters						
Input parameters		Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
PPDP		161.42	Undefined				<input type="checkbox"/>	Mass del Semipallet carico [kg]
MDP		144	Undefined				<input type="checkbox"/>	Massa di Legumi secchi nel semipallet [kg]

**Table S1.32**

Life cycle of the primary, secondary, and tertiary packaging materials (LC-1-3pack).

Input/output		Parameters					
Name		Status		Comment			
SDC -31 Life Cycle of I-II-III packaging		None					
Assembly	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 19 Assembly of I-II-III packages	1	p	Undefined				
Processes		Add		Amount	Unit	Dis	Comment
Waste/Disposal scenario		Comment					
SDC - 28 Disposal Scenario of I-II-III Packaging							
Additional life cycles	Number	Distribution	SD2 or 2SD	Min	Max	Comment	
SDC -32 Life Cycle of III packaging	1	Undefined					
Add							

**Table S1.33**

Life cycle of the PP semi-pallet (LC-3pack).

Input/output		Parameters					
Name		Status		Comment			
SDC -32 Life Cycle of III packaging		None					
Assembly	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 17 Assembly of Tertiary Packaging	1	p	Undefined				
Processes		Amount		Unit Distribution Comment			
Add							
Waste/Disposal scenario		Comment					
SDC - 27 Disposal Scenario of Tertiary Packaging							
Additional life cycles		Number		Distribution		SD2 or 2SD Min Max Comment	
Add							

# **A comprehensive study from cradle-to-grave on the environmental profile of malted legumes**

Mauro Moresi and Alessio Cimini

**SUPPLEMENTARY MATERIAL S2**

**Table S2.1** Input/output data for the conventional cultivation of the 3 varieties of legumes examined here (SDC, GPB, LO), as referred to a nominal land area of 1 ha. Air and water emissions were estimated according to the IPCC [45] and EPD® [46] guidelines.

Legume	SDC	GPB	OL	Unit
<b>Input/Output Parameter</b>				
Nominal non-irrigated land used (S)	1	1	1	ha
<b>Input</b>				
NPK Fertilizer	100.0	100.0	20.0	kg/(ha yr)
N	20.0	20.0	4.0	kg/(ha yr)
P	8.7	8.7	1.7	kg/(ha yr)
K	16.6	16.6	3.3	kg/(ha yr)
Poultry Manure	200.0	200.0	200.0	kg/(ha yr)
N	8.0	8.0	8.0	kg/(ha yr)
P	3.5	3.5	3.5	kg/(ha yr)
K	6.6	6.6	6.6	kg/(ha yr)
<b>Output</b>				
Fresh grain yield	1.71	1.26	1.26	Mg/(ha yr)
Average dry matter in grains harvested	0.88	0.88	0.88	g/g
Harvested annual dry matter grain yield	1.505	1.109	1.109	Mg/(ha yr)
Above ground biomass (AGR)	2.55	2.10	2.10	Mg/(ha yr)
Ratio of above-ground residues dry matter to harvested crop yield	2.1	2.1	2.1	g/g
Ratio of below-ground biomass to above-ground biomass (R <sub>BG-BIO</sub> )	0.19	0.19	0.19	g/g
N content of above-ground residues (N <sub>AG</sub> )	0.008	0.008	0.008	g/g
N content of below-ground residues (N <sub>BG</sub> )	0.008	0.008	0.008	g/g
Fraction of above-ground residues removed (Fra <sub>CRemoved</sub> )	0			%
Fraction of total area under crop annually renewed (Fra <sub>CRenew</sub> )	1			-
Below-ground residues (BG)	770.5	610.2	610.2	kg ss/(ha yr)
Nitrogen in crop residues (F <sub>CR</sub> )	26.57	21.71	21.71	kg N/(ha yr)
Fraction of synthetic N fertilizer volatilized as NH <sub>3</sub> + NO <sub>x</sub> (Fra <sub>CGASF</sub> )	0.11 (0.02-0.33)			(kg NH <sub>3</sub> -N+NO <sub>x</sub> -N)/(kg N)
Fraction of organic N fertilizer volatilized as NH <sub>3</sub> + NO (Fra <sub>CGASM</sub> )	0.21 (0.0-0.31)			(kg NH <sub>3</sub> -N+NO <sub>x</sub> -N)/(kg N)
Fraction of all N added lost through leaching off and runoff (Fra <sub>CLEACH</sub> )	0.24 (0.01-0.73)			kg N/(kg N)
N <sub>2</sub> O-N emissions per unit mass of N fertilizer added (EF <sub>1</sub> )	0.01 (0.001-0.018)			kg N <sub>2</sub> O-N/(kg N)
N <sub>2</sub> O-N emissions per unit mass of NH <sub>3</sub> and NO <sub>x</sub> emitted (EF <sub>4</sub> )	0.01 (0.002-0.018)			kg N <sub>2</sub> O-N/(kg NH <sub>3</sub> -N+kg NO <sub>x</sub> -N)
N <sub>2</sub> O-N emissions per unit mass of N leached off (EF <sub>5</sub> )	0.011 (0.0-0.020)			kg N <sub>2</sub> O-N/(kg N lisc/dilavato)
Direct N <sub>2</sub> O emissions F <sub>N2ODIR</sub> [(F <sub>S</sub> +F <sub>CR</sub> ) · EF <sub>1</sub> · 44/28]	0.857	0.781	0.530	kg N <sub>2</sub> O/(ha yr)
NH <sub>3</sub> +NO <sub>x</sub>	3.88	3.88	2.12	kg (NH <sub>3</sub> -N+NO <sub>x</sub> -N)/(ha yr)
F <sub>NH3-NOX</sub>	0.061	0.061	0.033	kg N <sub>2</sub> O/(ha yr)

Nitrate emissions in water [NO <sub>3</sub> <sup>-</sup> ]	13.10	11.93	8.09	kg NO <sub>3</sub> <sup>-</sup> -N/(ha yr)
F <sub>NO3-</sub>	0.226	0.206	0.140	kg N <sub>2</sub> O/(ha yr)
Indirect N <sub>2</sub> O emissions (F <sub>N2OIND</sub> )	0.287	0.267	0.173	kg N <sub>2</sub> O/(ha a)
N <sub>2</sub> O emissions from managed soils (F <sub>N2O</sub> = F <sub>N2ODIR</sub> + F <sub>N2OIND</sub> )	1.145	1.048	0.703	kg N <sub>2</sub> O/(ha a)
P emissions in water [0.05 kg P/ kg P applied] [46]	0.61	0.61	0.26	kg P/(ha a)
NO emissions in air [46]	0.731	0.731	0.178	kg NO-N/(ha a)

**Table S2.2**

Overall material balance of the fumigation process, cleaning/optical selection of harvested legumes, and storage of cleaned grains shown in Fig. 2, as related to the average yield of harvested fresh grain pulses. All symbols used to identify the various stream flows are given in the Nomenclature section.

Legume	S	GRs	GR	AIP		PH <sub>3</sub>	GRF	SP	GP	RP	PO+ER	SS		GPP	H <sub>2</sub> O <sub>v</sub>
	ha	kg/ha	kg	Comp.	g	g	kg	kg	kg	kg	kg	No.	kg	kg	kg
SDC	10	1710	17100	85.5	256.5	85.5	17100.2	2137.7	14962.5	769.5	1368.2	15.0	44.9	15007.4	598.5
GPB	8.5	1260	10710	53.6	160.7	53.6	10710.1	1338.9	9371.3	482.0	856.9	9.4	28.1	9399.4	374.85
LO	30	1260	37800	189.0	567.0	189.0	37800.4	12285.4	25515.0	4725.0	7560.4	25.5	76.5	25591.5	1020.6

Legume	GPPD	Seeds	GPD	SGP	MZ	SSU	SSU	RPS
	kg	kg	kg	kg	kg	No	kg	kg
SDC	14364.0	1300.0	13064.0	65.3	834.8	0.8	2.5	837.3
GPB	8996.4	850.0	8146.4	40.7	522.7	0.5	1.6	524.3
LO	24494.4	3000.0	21494.4	107.5	4832.5	4.8	14.5	4847.0

**Table S2.3**

Selling prices (sp) for the cleaned and selected grains of the legumes examined (SDC, GPD, LO) and by-products designated for animal husbandry (MZ) along with the total revenue, and allocation percentage of by-products (ALL<sub>MZ</sub>). All symbols used are given in the Nomenclature section.

<b>Legume</b>	<b>sp<sub>GPD</sub></b> [€/kg]	<b>sp<sub>MZ</sub></b> [€/kg]	<b>MZ</b> [kg]	<b>GPD</b> [kg]	<b>Total revenue</b> [€]	<b>ALL<sub>MZ</sub></b> [%]
SDC	3.6	0.1	834.8	13064	47113.9	0.18%
GPB	6.0	0.1	522.7	8146.4	48930.7	0.11%
LO	5.0	0.1	4832.5	21494.4	107955.2	0.45%

**Table S2.4**

Percentage fraction of the process and packaging materials discarded, as collected in the dry legume factory examined in this work.

<b>Processing and Packaging Materials discarded</b>	<b>Discarded Fraction (%)</b>
PE super-sacks	0
Dry legumes	0.5
<i>Primary packaging</i>	
PP bags	2.5
Paper label	0.5
Cardbord collar	0.5
Brass rivets	0.5
<i>Secondary packaging</i>	
Cartons (CAW)	1.0
Carton labels	0.3
Scotch tape	0.3
<i>Tertiary packaging</i>	
Damaged PP semi-pallet	0.2
Pallet adhesive label	0.5
Stretch & shrink film	0.5

**Table S2.5**

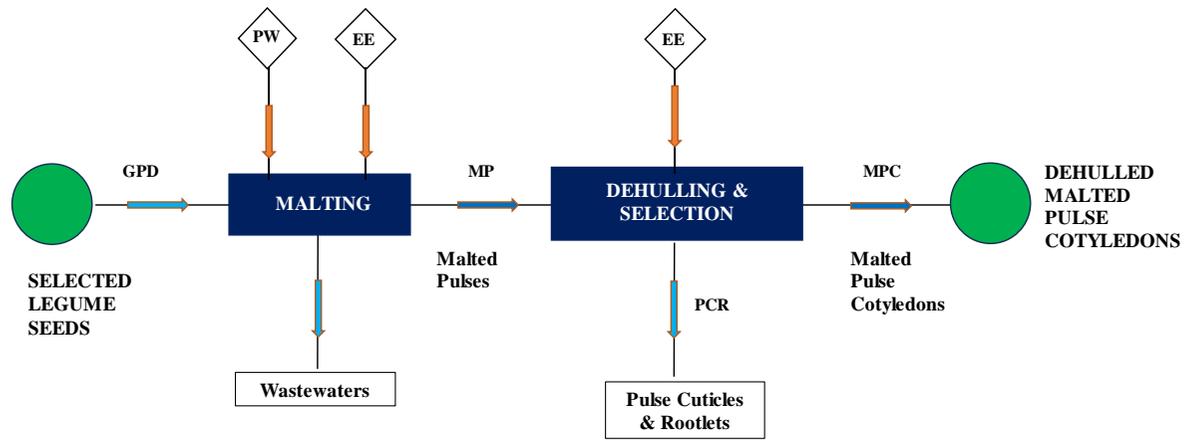
Overall material balance of the packaging process of cleaned pulse grains and its waste management process., as referred to the block diagram in Fig. 3. All symbols used to identify the various stream flows are given in the Nomenclature section.

<b>Legume</b>	<b>GPD</b>	<b>SGP</b>	<b>Bags</b>	<b>PP</b>	<b>N<sub>2</sub></b>	<b>CAV</b>	<b>RO</b>	<b>ET</b>	<b>SPP</b>	<b>SCAV</b>	<b>SRO</b>	<b>SET</b>
	[kg]	[kg]	No.	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]
SDC	13064.0	65.3	25997.4	133.2	130.0	151.5	8.7	21.1	3.2	0.754	0.043	12.7
GPB	8146.4	40.7	16211.3	83.1	81.1	94.5	5.4	13.2	2.0	0.470	0.027	7.9
LO	21494.4	107.5	42773.9	219.2	213.9	249.3	14.3	34.7	5.3	1.240	0.071	20.9
<b>Legume</b>	<b>LCI</b>		<b>CA</b>		<b>SCA</b>		<b>EC</b>	<b>SEC</b>	<b>SC</b>	<b>SSC</b>		
	[kg]		No.	[kg]	[kg]		[kg]	[kg]	[kg]	[kg]		
SDC	13426.5		2166.4	660.8	6.5		4.3	0.01	8.7	0.03		
GPB	8372.5		1350.9	412.1	4.1		2.7	0.01	5.4	0.02		
LO	22090.8		3564.5	1087.2	10.8		7.2	0.02	14.3	0.04		
<b>Legume</b>	<b>LCII</b>		<b>PAL</b>		<b>SPAL</b>		<b>EP</b>	<b>SEP</b>	<b>FP</b>	<b>SFP</b>	<b>LCIII</b>	
	[kg]		no.	[kg]	[kg]		[kg]	[kg]	[kg]	[kg]	[kg]	
SDC	14093.8		90.3	452.2	0.9		0.6	0.003	26.1	0.13	14571.6	
GPB	8788.5		56.3	282.0	0.6		0.4	0.002	16.3	0.08	9086.5	
LO	23188.7		148.5	744.1	1.5		0.9	0.005	42.9	0.21	23974.9	
<b>Legume</b>	<b>RPL'</b>		<b>RCC'</b>		<b>RM'</b>		<b>MZ</b>		<b>PO+E</b>			
	[kg]		[kg]		[kg]		[kg]		[kg]			
SDC	49.2		20.0		0.043		834.8		1368.2			
GPB	30.8		12.5		0.027		522.7		856.9			
LO	83.6		32.9		0.071		4832.5		7560.4			

**Table S2.6**

Overall material balance of the malting, cleaning, dehulling and packaging processes of cleaned pulse grains and their waste management process, as referred to the block diagrams in Figures S1 and 3. All symbols used to identify the various stream flows are given in the Nomenclature section.

<b>Legume</b>	<b>GPD</b>		<b>MP</b>				<b>PCR</b>				<b>MPC</b>					
	[kg]		[kg]				[kg]				[kg]					
SDC	13064.0		13064.0				1920.4				11143.6					
GPB	8146.4		8146.4				1197.5				6948.9					
LO	21494.4		21494.4				3159.7				18334.7					
<b>Legume</b>	<b>SMP</b>	<b>PP</b>		<b>N<sub>2</sub></b>	<b>CAV</b>	<b>RO</b>	<b>ET</b>	<b>SPP</b>	<b>SCAV</b>	<b>SRO</b>	<b>SET</b>	<b>MPCI</b>				
	[kg]	No.	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]				
SDC	55.7	22175.7	113.7	110.9	129.3	7.4	18.0	2.8	0.643	0.037	10.8	11452.8				
GPB	34.7	13828.3	70.9	69.1	80.6	4.6	11.2	1.7	0.401	0.023	6.8	7141.7				
LO	91.7	36486.1	187.0	182.4	212.7	12.2	29.6	4.6	1.058	0.061	17.8	18843.5				
<b>Legume</b>	<b>CA</b>		<b>SCA</b>	<b>EC</b>	<b>SEC</b>	<b>SC</b>	<b>SSC</b>	<b>MPCII</b>	<b>PAL</b>		<b>SPAL</b>	<b>EP</b>	<b>SEP</b>	<b>FP</b>	<b>SFP</b>	<b>MPCIII</b>
	No.	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	No.	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]
SDC	954.4	291.1	2.9	1.9	0.01	3.8	0.01	11746.8	77.0	385.8	0.8	0.5	0.002	22.2	0.11	12154.4
GPB	595.1	181.5	1.8	1.2	0.00	2.4	0.01	7325.0	48.0	240.6	0.5	0.3	0.001	13.9	0.07	7579.2
LO	1570.3	479.0	4.7	3.2	0.01	6.3	0.02	19327.1	126.7	634.7	1.3	0.8	0.004	36.6	0.18	19997.8
<b>Legume</b>	<b>RPL'</b>				<b>RCC'</b>			<b>RM'</b>			<b>MZ</b>		<b>PO+E</b>			
	[kg]				[kg]			[kg]			[kg]		[kg]			
SDC	48.6				14.4			0.037			2745.6		1368.2			
GPB	30.4				9.0			0.023			1714.2		856.9			
LO	82.6				23.6			0.061			7976.4		7560.4			



**Figure S2.1.** Block diagram of the malting, dehulling and selection process of selected legume seeds. For all symbols refer to the Nomenclature section.