Application of Data Envelopment Analysis to Assess Performance Efficiency of Eight Faba Bean Varieties

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ABSTRACT

Faba bean (*Vicia faba* L.) seeds are generally large which limits its adoption as cover crop and/or dual purpose cover crop/cash crop due to the high seed cost. The purpose of this study was to apply data envelopment analysis (DEA) by using seed size as input and fresh pod, fresh seed, and L-Dopa yield as output to evaluate efficiency of eight faba bean varieties. Eight faba bean varieties were evaluated in a 2-yr study. Four common methods of DEA were used for ranking faba bean varieties. Aquadulce and Delle Cascine out-yielded other varieties in both years. Averaged over 2 yr Aquadulce and Delle Cascine produced 16.15 and 16.27 Mg ha^{-1}fresh pod, respectively. However, Aquadulce had 21% lower seed size than Delle Cascine which significantly reduces the cost of production. L-Dopa yield ranged from 4 kg ha^{-1} in Sweet Lorane to 46 kg ha^{-1} in Aquadulce. Although no significant difference was found in fresh pod yield and fresh seed yield of Aquadulce and Delle Cascine, Aquadulce ranked first in both years while Delle Cascine ranked fourth in 2015 and third in 2016 due to its larger seed size and lower L-Dopa. Bell bean and Sweet Lorane had the smallest seed size yet their efficiency ranked last due to their low fresh pod yield, fresh seed yield, and L-Dopa yield. Results revealed that DEA could successfully use multiple traits in a single mathematical model without the need for the specification of tradeoffs among multiple measurements.

Core Ideas

- Seed size along with yield should be considered for evaluation of faba bean varieties.
- Data envelopment analysis can be implemented for ranking the efficiency of faba bean varieties.
- Varieties ranked high by data envelopment analysis models can promote faba bean production in the Northeast.

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Faba bean is a cool season legume crop, which originated in the Middle East in the pre-historic period where it has been used as a main source of protein for human and animal nutrition. Faba bean is the fourth most important pulse crop in the world due to its richness in protein, carbohydrate, B-group vitamins, and minerals (Crépon et al., 2010). Faba bean is considered an important dietary component used by many ethnic groups, especially Portuguese-speaking citizens. Massachusetts has the largest population of Portuguese-speaking people in the United States. The community comprises people from Portugal, the Azores, Cape Verde, and a growing Brazilian population, estimated by the Brazilian Consulate in Boston at approximately 250,000 in 2013 (Etemadi et. al., 2015). However, faba bean is not currently grown in New England, partly due to its large seed size and relatively low yield which makes it non-competitive compared with other legumes. Currently only two varieties of faba bean are available to the Northeast growers where their yields are relatively low and the seed cost is high due to their large seed size. Projected population density of grain crops is traditionally determined by seeding rate per unit area and is related to the number of seeds per unit weight (kg). Therefore seeding rate of cultivars with smaller seed size is significantly lower than those with larger seeds which in turn influence the cost of production.

Due to its diverse and significant ecological services (Köpke and Nemecek, 2010) faba bean has increasingly received attention and is now widely used in many regions of the world as a source of food and also as a break crop in cereal crop production to minimize the occurrence of cereal cyst nematode (*Heterderaavenae*) (Sattell et. al., 1998) and some soil-borne pathogens (Landry et. al., 2016). Faba bean has been identified for its efficient N_2 fixation capacities among the cool season pulses (Herridge et. al., 1994; Mekkei, 2014). Reports indicated that faba bean can fix between 53 and 330 kg N ha^{-1} (Helvacıoğlu and Şehirali, 2001; Galloway et. al., 2004; Visalli, 2015) depending on management and environmental conditions. In New England, faba bean can be seeded as early as mid-March if soil is dry enough for cultivation practices and be harvested in time for planting an additional crop due to its

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Abbreviations: AR, assurance region; BCC, Banker, Charnes, and Cooper model; CCR, Charnes, Cooper, and Rhodes; DEA, data envelopment analysis; DMU, decision-making units; FG, Färe and Grosskopf ;GAMS, generalized algebraic modeling system; L-Dopa, L-3, 4-dihydroxyphenylalanine; PFW, pod fresh weight; SFW, seed fresh weight; ST, Seiford and Thrall.

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relatively short growing season. When planted early, some marketable pods can be harvested in late June and N-rich residues be incorporated into soil as green manure. Alternatively, faba bean can be sown after harvesting winter grains or a spring crop as a dual purpose, that is, cash crop/cover crop until it is winter killed (Etemadi et. al., 2015).

Faba bean also has been identified as a rich source of natural L-Dopa which is the precursor to the neurotransmitters dopamine, norepinephrine, and epinephrine collectively known as catecholamines (Randhir and Shetty, 2004; Singh et al., 2013; Mohseni and Golshani, 2013). L-Dopa elevates dopamine concentrations in the brain thus traditionally it has been used for curing Parkinson's disease (Hiroshima et. al., 2014). Faba bean varieties vary considerably in L-Dopa content. For example, Etemadi et al. (2014) reported that L-Dopa concentrations in different varieties varied between 7.6 to 10.9 g kg^{-1}.

Data envelopment analysis is a non-parametric method that uses linear programming to evaluate the performance of decision-making units (DMUs) with multiple inputs and outputs. It has opened up possibilities for use in cases which have been resistant to other approaches because of the complex and often unknown nature of the relations between the multiple inputs and outputs involved in many of their activities Data envelopment analysis was first introduced by Charnes et al. (1978) and since then a continuous growth in its implication has been observed. The DEA has the ability to model multiple-input and multiple-output relationships without a priori underlying functional form assumption. This ability provides wide application areas such as in agriculture, banking, education, environment, healthcare, energy, manufacturing, transportation, and supply chain management (Emrouznejad et al., 2008). Researchers have successfully used DEA to analyze the production efficiency (Huang and Hu, 2006), productivity (Aldaz and Millán, 2003), land use (Toma et. al., 2015), and irrigation (Díaz et al., 2004). For a comprehensive survey on DEA applications from 1978 to 2010, see Liu et al. (2013). In general, DEA models minimize "inputs" and maximize "outputs"; where smaller levels of the former and larger levels of the latter represent better performance or efficiency (Cook et. al., 2014). The most popular DEA models were introduced by Charnes et al. (1978) (CCR model), Banker et al. (1984) (BCC model), Färe and Grosskopf (1985) (FG model), and Seiford and Thrall (1990) (ST model). The main difference between above DEA models can be summerized as the CCR model is constant returns to scale, the BCC model is variable returns to scale, the FG model is non-increasing returns to scale, and the ST is non-decreasing returns to scale (Foroughi and Shureshjani, 2016). For more details about qualitative and quantitative aspects of returns to scale in DEA models, readers are referred to Banker et al. (2011).

Yu et al. (1996 a, 1996b) proposed a generalized model that included the above mentioned popular DEA models. In agriculture, selection process of inputs is important because the outputs such as productivity depend on the input consumption. However, when additional information or assumptions are available, some weights need to be restricted. Therefore in this regard a DEA problem with an assurance region should be considered. A DEA problem with an assurance region (DEA/AR) first was introduced by Thompson et al. (1990) and made DEA more applicable. In crop production, yield is acknowledged as having a positive correlation with economic efficiency.

The main objective of this research was to evaluate the performance (economic yield) of eight faba bean varieties based on their seed size, pod fresh weight (PFW) and seed fresh weight (SFW) and L-Dopa yield. Four different DEA models were used to assess the performance efficiency of these spring-sown faba bean varieties in Massachusetts.

MATERIALS AND METHODS

Farm Experiment

Eight varieties of faba bean including Bell Bean, Early Violletto, Aquadulce, Delle Cascine, Windsor, Sweet Lorane, Early White, and D'Aquadulce were selected for this study based on their past performance when sown in early spring at the research site (Etemadi et al., 2015). The seed size of the varieties were determined by taking the average of five sets of 100-seeds and were ranged from 51 g per 100 seeds (bell bean) to 392 g per 100 seeds (D'Aquadulce). Seeds were hand-planted in 15 Apr. 2015 and 17 Apr. 2016 at the University of Massachusetts Crops and Animal Research and Education Center in South Deerfield (42°28′37″ N, 720°36′2″ W). The soil type was a Hadley fine sandy loam (nonacid, mesic Typic Udifluvent) with pH of 6.7, organic matter content of 12 g kg^{-1}, N, P, K, and Ca content of 3, 9, 73, and 868 mg kg^{-1} (Morgan, 1941), respectively. These nutrients content were considered adequate (New England Vegetable Management Guide, 2016). Therefore no additional fertilizer was applied to the experimental plots. A complete randomized block design with four replications was used. Research plots consisted of three rows, 5 m long and 0.76 m apart. Space between the plants within the rows was 15 cm. Three meters from the middle rows (2.28 m^2) from each plot was randomly selected and marked as final harvest area. Pods of plants in final harvest areas were harvested manually three times beginning on 7 July 2015 and 10 July 2016 for determination of pod and seed yield. Weeds were controlled three times prior to canopy closure using a hand rotivator.

Measurements

Faba bean yield including PFW and SFW were determined. Seed cost was calculated based on 60,000 seeds ha^{-1}, number of seeds kg^{-1}, and the cost of purchased seeds. L-Dopa concentration in seeds was measured at physiological maturity and presented as L-Dopa yield (SFW × L-Dopa concentration). Seed samples were oven dried for 36 h at 55°C. Dried samples were ground fine to pass through a 0.42 mm screen before extraction.

High Performance Liquid Chromatography Procedure

We immersed 200 mg of ground samples in 95% ethanol and then kept in a freezer for 72 h. Samples were homogenized using a tissue tearer. Samples were centrifuged at 13,000 rpm for 10 min. The liquid portion was left under hood until the ethanol evaporated. The residue was dissolved in buffer solution and left in fridge until particles settled. The supernatant was passed through a 0.45 μm syringe filter and analyzed using an high performance liquid chromatography (HPLC) (Shimadzu Prominence HPLC with DAD detector, Phenomenex Gemini C18 column). Four concentrations of stock solution (50, 100, 200, 400 mg L^{-1}) were used and diluted and injected with the mobile phase. The calibration curve was obtained by plotting the absorbance area vs. the concentrations of the standard solution.

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Data Envelopment Analysis

Generalized Data Envelopment Analysis with Assurance Region

Data envelopment analysis (Eq. [1]) was used as a tool in ranking varieties based on three traits that had highest priority for our assessment.

Assume x_{ij} and y_{rj} are the amount of the ith input and rth output of jth DMU$_j$, respectively. Then the generalized DEA model was formulated as following (Yu et al., 1996a, 1996b):

$$
\begin{aligned}
\max\ & z=\sum_{r=1}^{s}u_r y_{ro}-\delta_1 u_0 \\
\text{s.t.}\ & \sum_{i=1}^{m}v_i x_{io}=1 \\
& \sum_{r=1}^{s}u_r y_{rj}-\sum_{i=1}^{m}v_i x_{ij}-\delta_1 u_0\le 0,\ j=1,\dots,n \\
& \delta_1\delta_2(-1)^{\delta_3}u_0\ge 0,\ v_i,u_r\ge 0,\ i=1,\dots,m,\ r=1,\dots,s
\end{aligned}
\qquad [1]
$$

where δ_1, δ_2, and δ_3 are binary parameters:

1. If $\delta_1 = 0$, then the generalized DEA model is reduced to the CCR model.
2. If $\delta_1 = 1$ and $\delta_2 = 0$, then the generalized DEA model is reduced to the BCC model.
3. If $\delta_1 = \delta_2 = 1$ and $\delta_3 =0$, then the generalized DEA model is reduced to the FG model.
4. If $\delta_1 = \delta_2 = \delta_3 = 1$, then the generalized DEA model is reduced to the ST model.

In theory, DEA models allow each DMU to select the weights that are most favorable to themselves in calculating the ratio of the virtual output to the corresponding virtual input. However, the weights of inputs and outputs must be kept in some ranges to be applicable to agricultural usage. Therefore, the concept of the assurance region (AR) was developed to restrict some weights to reasonable ranges (Thompson et. al., 1990, 1992). These restrictions were applied to DEA models to prevent DMUs from ignoring and/or relying too much on any input or output. Zhou et al. (2012) developed the following model for AR (Eq. [2]).

$$
\begin{aligned}
\max\ & z=\sum_{r=1}^{s}u_r y_{ro}-\delta_1 u_0 \\
\text{s.t.}\ & \sum_{i=1}^{m}v_i x_{io}=1 \\
& \sum_{r=1}^{s}u_r y_{rj}-\sum_{i=1}^{m}v_i x_{ij}-\delta_1 u_0\le 0,\ j=1,\dots,n \\
& C_{pq}^{L}\le\frac{v_q}{v_p}\le C_{pq}^{U},\ 1\le p\prec q=2,\dots,m \\
& D_{pq}^{L}\le\frac{u_q}{u_p}\le D_{pq}^{U},\ 1\le p\prec q=2,\dots,s \\
& \delta_1\delta_2(-1)^{\delta_3}u_0\ge 0,\ v_i,u_r\ge 0,\ i=1,\dots,m,\ r=1,\dots,s
\end{aligned}
\qquad [2]
$$

In this study, we assumed that $0\le C_{pq}^{L}\prec C_{pq}^{U}$ and $0\le D_{pq}^{L}\prec D_{pq}^{U}$.

From the generalized DEA model (model 1), parameter u_0 in the CCR model is zero; in the BCC model is a free in sign variable; in the FG model is a non-negative variable; and in the ST model is a non-positive variable. Thus the following relations were considered to obtain the efficiency when using these four models:

The efficiency of a DMU from the CCR model is less than or equal to its efficiency from the FG or the ST model.

The efficiency of a DMU from the FG or the ST model is less than or equal to its efficiency from the BCC model.

The efficiency of a DMU from the BCC model with a positive u_0 will be the same as its efficiency from the FG model.

The efficiency of a DMU from the BCC model with a negative u_0 will be the same as its efficiency from the ST model.

The efficiency of a DMU from the FG or ST model with $u_{0=0}$ will be the same as its efficiency from the CCR model.

Statistical Analysis

Proc GLM (SAS Institute, 2003) was used for analysis of variance. Effects were considered significant at $P \le 0.05$ by the F test, and when the F test was significant, Fisher's Least Significant Difference Test (LSD) was used for mean separations.

RESULTS

Fresh Pods, Fresh Seeds, and L-Dopa Yield

A significant year by dependent variables including PFW, SFW, and L-Dopa was detected; therefore, data was analyzed by year. Bell bean performed poorly in 2016 thus it was eliminated from variety evaluation in the second year of the experiment. Pod fresh weight, seed fresh weight, and L-Dopa of faba bean varieties harvested in 2015 and 2016 are presented in Tables 1 and 2, respectively. On average, PFW, SFW, and seed/pod ratio were significantly higher in 2015 compared with 2016. This was mainly attributed to the wetter and warm but slightly cooler conditions in 2015 (Table 3), particularly during the months of June and July when pod formation and pod filling of faba bean normally takes place in northeastern United States. The response of the tested varieties to growing conditions varied significantly, but Aquadulce and Delle Cascine out-yielded other varieties in both years (Tables 1 and 2). Windsor is the common variety available to the growers in the Northeast. However, our results revealed that Aquadulce yielded roughly threefold higher than Windsor while its seed size was 15% smaller thus its seed cost is also lower. Moreover, L-Dopa yield among the tested varieties varied dramatically and ranged from 4.0 to 46.0 kg ha^{-1} in 2015 and 2.8 to 30 kg ha^{-1} in 2016. Higher L-Dopa in 2015 compared with 2016 can be attributed to higher fresh pod yield which was 12% higher averaged over all varieties (Tables 1 and 2).

Varieties Efficiency

In this study we used four major traits including seed size, PFW, SFW, and L-Dopa yield for ranking the varieties using the DEA/AR model. To analyze the data by the model, the inputs and outputs of the DEA model were defined. The PFW, SFW, and L-Dopa values were used directly as the outputs in all four models with no transformation required where the larger numbers considered more favorable. Seed size however, is a quantity where too large and/or too small values cannot be considered desirable. Hence, seed size values were converted into a set of data before being used. An average of the smallest

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Table 1. Seed size, pod fresh weight (PFW), seed fresh weight (SFW), and L-3, 4-dihydroxyphenylalanine (L-Dopa) yield of faba bean in 2015.

Variety	Seed size	Deviation from the avg. seed size (input)	PFW (output 1)	SFW (output 2)	L-Dopa (output 3)
	g 100 seed^{-1}		——— Mg ha^{-1}	———	kg ha^{-1}
Bell Bean	51	−170.5	3.73cd†	1.46c	13.6e
Sweet Lorane	68	−153.5	2.05d	0.52d	4.0f
Early White	253	31.5	11.86b	3.82b	28.6c
Aquadulce	265	43.5	16.94a	6.67a	46.0a
Early Violletto	280	58.5	13.52b	4.98ab	21.9cd
Windsor	311	89.5	5.77c	2.13bc	15.3de
Delle Cascine	335	113.5	17.04a	5.28a	37.5b
D'Aquadulce	392	170.5	6.22c	1.81c	13.5e

† Values within a column followed by the same letter do not differ significantly ($p < 0.05$).

Table 2. Seed size, pod fresh weight (PFW), seed fresh weight (SFW), and L-3, 4-dihydroxyphenylalanine (L-Dopa) yield of faba bean in 2016.

Variety	Seed size	Deviation from the avg. seed size (input)	PFW (output 1)	SFW (output 2)	L-Dopa (output 3)
	g 100 seed^{-1}		——— Mg ha^{-1}	———	kg ha^{-1}
Sweet Lorane	68	−162	1.34e†	0.36d	2.8c
Early White	253	23	10.59c	2.08c	15.6b
Aquadulce	265	35	15.37a	4.35a	30.0a
Early Violletto	280	50	11.25b	3.45b	15.2b
Windsor	311	81	5.02d	1.84c	13.3b
Delle Cascine	335	105	15.50a	4.12a	29.3a
D'Aquadulce	392	162	5.44d	1.79c	13.4b

† Values within a column followed by the same letter do not differ significantly ($p < 0.05$).

(Bell bean) and the largest seed size (D'Aquadulce) was calculated and seed size deviation of all varieties from the average was determined and used as input. The smaller the deviation from the average value was considered optimum. The adjusted data for seed size as input to the DEA model is included in Tables 1 and 2. In summary, there were one input (deviation from the average seed size) and three outputs including PFW, SFW, and L-Dopa (kg ha^{-1}) in the DEA models.

The ARs should be determined based on experts' opinions or other logic explanations. In the current study the ARs were defined based on authors'experience and considered as Eq. [3].

$$\frac{1}{3} \leq \frac{u_2}{u_1} \leq 3 \quad \text{and} \quad \frac{1}{3} \leq \frac{u_3}{u_2} \leq 3 \qquad [3]$$

We utilized the GAMS software for running the model. In this study four models, that is, CCR, BCC, FG, and ST were used for evaluation of the efficiency of the faba bean varieties in 2015 and 2016 (Tables 4–7).The results indicated that Aquadulce had the highest performance efficiencies in all four models in 2015 (Tables 4 and 5) and 2016 (Tables 6 and 7) followed by Early White. Interestingly, Delle Cascine yielded similar or better than Aquadulce and Early White varieties however due to its larger seed size, lower seed/pod ratio, and lower L-Dopa content it was ranked fourth in the efficiency evaluation list. On the other hand although Early White ranked second in almost all four models, its PFW, SFW, and L-Dopa yields were dramatically lower than Aquadulce and therefore the ranking might be misleading. This clearly indicates that DEA can be used efficiently when the number of testing faba bean varieties is fairly high.

Table 3. Precipitation and growing degree days (GDD) during faba bean growing season in 2015, 2016, and norm (50 yr average) for the experimental site.

	Precipitation		GDD†		50-yr mean
Month	2015	2016	2015	2016	Precipitation
	—— mm ——				mm
April	55	50	206.7	234.1	77
May	49	74	751.9	584.2	84
June	183	50	773.5	823.1	112
July	14	82	994.0	1040.7	90

† GDD = (T_{max}+ T_{min})/2– T_{base} where $T_{base}$is 4.4°C (Etemadi et al., 2015).

DISCUSSION

Although numerous ecological services from faba bean have been documented (Köpke and Nemecek, 2010; Jensen et. al., 2010) and despite an increasing market for fresh faba bean in southern New England, its cultivation has been neglected thus markets in this region are relying on imported fresh faba bean from Mexico and other states. Large seeds of many faba bean varieties, at least those that are currently available to the growers in the Northeast, should be considered as one of the major factors that limits faba bean production. The authors agree with Landry et al. (2016) that potential agronomic benefits, including the economics as well as various ecological services of faba bean should be explored further.

Despite no statistical differences between Aquadulce and Delle Cascine in regard to PFW, SFW, and L-Dopa content, Delle Cascine ranked fourth in 2015 and third in 2016 compared with Aquadulce which came first in terms of variety efficiency in both years. This was primarily due to the smaller seed size of Aquadulce which was 21% lower than Delle Cascine. In other words while having similar yield, Aquadulce was selected as a better choice than Delle Cascine especially when faba bean is grown primarily as cover crop and/or dual purpose cash/cover crop.

Table 4. Efficiency ranking of faba bean varieties using Charnes, Cooper, Rhodes (CCR) and Färe and Grosskopf (FG) models (2015).

DMU† (Variety)	Efficiency CCR and FG models	Rank	Input weight	Output weights		
			v_1	u_1	u_2	u_3
Bell Bean	0.056259	7	0.005865	0.000007	0.000020	0.000061
Sweet Lorane	0.032948	8	0.006515	0.000015	0.000005	0.000002
Early White	0.946632	2	0.031746	0.000072	0.000024	0.000008
Aquadulce	1.000000	1	0.022989	0.000052	0.000017	0.000006
Early Violletto	0.589044	3	0.017094	0.000039	0.000013	0.000004
Windsor	0.164294	5	0.011173	0.000025	0.000008	0.000003
Delle Cascine	0.376081	4	0.008811	0.000020	0.000007	0.000002
D'Aquadulce	0.090841	6	0.005865	0.000013	0.000004	0.000001

† DMU, decision-making units.

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Table 5. Efficiency ranking of faba bean varieties using Banker, Charnes, and Cooper (BCC) and Seiford and Thrall (ST) models (2015).

DMU† (Variety)	Efficiency BCC and ST models	Rank	Input weight	Output weights			Free in sign variable
			v_1	u_1	u_2	u_3	u_0
Bell Bean	0.184751	6	0.005865	0.000000	0.000000	0.000000	–0.184751
Sweet Lorane	0.205212	5	0.006515	0.000000	0.000000	0.000000	–0.205212
Early White	1.000000	1	0.031746	0.000000	0.000000	0.000000	–1.000000
Aquadulce	1.000000	1	0.022989	0.000020	0.000061	0.000020	–0.252927
Early Violletto	0.615794	2	0.017094	0.000015	0.000045	0.000015	–0.188074
Windsor	0.351955	4	0.011173	0.000000	0.000000	0.000000	–0.351955
Delle Cascine	0.376964	3	0.008811	0.000018	0.000006	0.000002	–0.047094
D'Aquadulce	0.184751	6	0.005865	0.000000	0.000000	0.000000	–0.184751

† DMU, decision-making units.

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Table 6. Efficiency ranking of faba bean varieties using Charnes, Cooper, Rhodes (CCR) and Färe and Grosskopf (FG) models (2016).

DMU† (Variety)	EfficiencyCCR and FG models	Rank	Input weight	Output weights		
			v_1	u_1	u_2	u_3
Sweet Lorane	0.018692	6	0.006173	0.000004	0.000011	0.000022
Early White	1.000000	1	0.043478	0.000043	0.000014	0.000089
Aquadulce	1.000000	1	0.028571	0.000016	0.000049	0.000102
Early Violletto	0.532079	2	0.020000	0.000012	0.000035	0.000025
Windsor	0.160575	4	0.012346	0.000007	0.000021	0.000136
Delle Cascine	0.333162	3	0.009524	0.000009	0.000003	0.000034
D'Aquadulce	0.082388	5	0.006173	0.000006	0.000002	0.000068

† DMU, decision-making units.

Table 7. Efficiency ranking of faba bean varieties using Banker, Charnes, and Cooper (BCC) and Seiford and Thrall (ST) models (2016).

DMU† (Variety)	Efficiency BCC and ST models	Rank	Input weight	Output weights			Free in sign variable
			v_1	u_1	u_2	u_3	u_0
Sweet Lorane	0.141975	5	0.006173	0.000000	0.000000	0.000000	–0.141975
Early White	1.000000	1	0.043478	0.000000	0.000000	0.000000	–1.000000
Aquadulce	1.000000	1	0.028571	0.000000	0.000000	0.000030	–0.657143
Early Violletto	0.558948	2	0.020000	0.000201	0.000602	0.000021	7.553890
Windsor	0.283951	4	0.012346	0.000000	0.000000	0.000000	–0.283951
Delle Cascine	0.333162	3	0.009524	0.000000	0.000000	0.000034	–0.219048
D'Aquadulce	0.141975	5	0.006173	0.000000	0.000000	0.000000	–0.141975

† DMU, decision-making units.

L-Dopa concentration in fresh seeds of the tested varieties were higher in 2016 because growing conditions was drier and warmer than 2015. L-Dopa is a secondary metabolite and it is well documented that accumulation of secondary metabolites in plants strongly interacts with growing conditions and environmental stresses (Keshavarz Afshar et al., 2015). Nevertheless despite higher L-Dopa concentrations in 2016 (averaged across all varieties) since SFW in 2015 was roughly 30% more than in 2016, L-Dopa yield was higher in 2015 compared with 2016.

There is a dramatic variation in seed size of faba bean varieties (Duc, 1997; Landry et al., 2016). In the current study with a limited number of varieties, the seed of D'Aquadulce was almost 7.7 and 5.8-fold larger than bell bean and Sweet Lorane, respectively. Such significant variation makes faba bean a unique legume crop when it comes to variety evaluation. For example in common bean (*Phaseolus vulgaris* L.) (Peksen and Gulumser, 2005; Sabokdast and Khyalparast, 2008), or chickpea (*Cicer arietinum* L.) (Atta et. al., 2008), variety selection were simply based on seed yield which is the highest contributor to the overall yield. However in faba bean, due to the large variation in seed size, economic yield which includes seed cost must also be considered. In the current study replacing Windsor (the current available variety in the Northeast) with Aquadulce seems an easy decision. Aquadulce has a smaller seeds (265 g 100 seed^{-1} vs. 311 g 100 seed^{-1}) therefore it requires a lower seeding rate (84 vs. 102 kg ha^{-1}) and lower seed cost (US$538 vs. $727 ha^{-1}), and had a higher seed yield (1925 vs. 695 g dry seed). However, in other examples the selection of a variety could be more complicated where the seed cost of a variety might be less but its yield is also lower. The selection becomes even more complicated when L-Dopa yield is among the goals of faba bean cultivation.

The results of the current study indicated that DEA can be used efficiently especially when the number of testing faba bean varieties is fairly high. Varieties ranked high by DEA models can be significantly used to promote faba bean production in the Northeast.

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