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Optimized Consumption Behavior of Sewing Threads for Women's Underwear

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Abstract:

This work deals with the optimization of consumed thread to seam women's underwear in the studied design of interest. Indeed, some influential input parameters such as needle and bobbin or looper thread tensioner adjustment, number of layers, fabric thickness, stitch density and sewing thread quality, on the consumption behavior of sewing thread based on knitted fabric to made women's underwear are investigated and optimized. Based on basic stitch structures to sew female underwire bra and panty, relationships between the consumption behavior of sewing thread and the investigated inputs are derived to decrease the consumption values. Findings show the effectiveness of the metaheuristic techniques to allow industrials to minimize accurately their consumptions of sewing thread to made female underwear. It revealed that women's underwire bra consumes more sewing threads than panty. Although, the increase of tension of threads to sew female underwear's decreases the consumed amount of threads, the increase of other studied parameter values widely encourages the consumption values, especially for seams based on chain stitch types. According to the comparative results obtained, this metaheuristic method gives accurate finding values of the consumption within the best combination of input parameters. Therefore, compared to experimental results and regarding the low consumption values obtained, it may be concluded that the both methods give good results except the PSO method is slightly more accurate than the GA method. The PSO method can widely decrease and predict the consumed thread amount, studied inputs and outputs parameters.

Keywords: *Women's underwear; Underwire bra, Female panty; Metaheuristic optimization.*

1. Introduction

Underwear is after all a product and its consumption will depend upon the taste of each woman as manifested by her habitus. Thus, we must see both its material as well as its symbolic value to consumption. Indeed, a woman's habitus (body shapes, various dispositions, taste, and the way that these dispositions mark woman's perceptions of objects or practices) enormously affect the choices she makes in underwear [1]. Although its importance, in literature academic, underwear is largely neglected part of women's clothing which, ways underwear is more interesting in the sense that it is hidden from view but still appears to have considerable social/discursive importance. There is only limited research on the consumption of look at this intimate aspect of material culture. Jantzen et al. [2, 3] have studied on how special and delicate underwear i.e. lingerie connects with women identity are the most prominent empirical studies that look at this intimate aspect of material culture. Even though other aspects of dress, pants and jackets have been given a lot of attention, as a means of identity construction, in the studies of consumption, and the consumption of other everyday objects have also been the focus of scholarly research, at least recently, underwear as a means of sewing thread consumption has been largely ignored. Due to its values, it represents a great importance for the industrial as well as the consumer. Furthermore, despite the fact that

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underwear is ostensibly hidden from view, a large number of women consumers spend a great amount of money on buying underwire or bras and panties and invest substantial effort in determining any given occasion [2, 3].Nonetheless, consuming female lingerie such as bras and panties with the purpose of experiencing feminine identity is a matter of controlling your bodily performance in social life [4, 5]. Generally, underwear specialists are, relatedly, involved in creating products (such as the push-up bra, minimizer bra, sports bra and others) that target specific segments of the market such as pregnant women or women doing sports; different types of underwear that are targeted to support women's in their different life stages or during specific activities.

Women's consumption of lingerie may enhance their experience of inter- and intra-psychological identity [3]. Besides, to attempt this goal and traduce a sexy psychological feeling, the underwear's garment should reach a relevant compromise between quality (comfort, lowest defaults, good shapes, high quality of sewing threads, sexy and original patterns, etc.) with low sewing thread consumption. In fact, sewing lingerie and underwear particularly has never been easier for many reasons [6]. Firstly, the schedule assemblies of the overall underwire seem long needing several steps to seam garments. Secondly, the field of fashion is a system that adapts to as well as producing social imperatives, e.g. the introduction of strings or thongs that resulted from the need for invisible underwear to better support outerwear, specifically a sit became tighter and more revealing. Thirdly, the underwear's pattern making systems are not suitable for each body shape because for each pattern, different results are acquired increasing complexity of studied underwire patterns and fabrics [1]. Thus, the consumption of underwear can also be seen as a negotiation within a structured system. However, because it is mostly hidden, not visible in everyday life practices, it is even more interesting to pay more attention to this negotiation between the structuring system and agency in terms of the choices of underwear that each woman makes. Besides, the fabric of lingerie is warp and weft knitted samples which still delicate and needs particularly more attentive due to its high extensibility, deformations and high price of fabrics. In spite of these difficulties during seam processes particularly, some researchers proposed the use strictly of the guidance of underwear's patterns to be sewed and the different shapes of the undies suit most body types and there are different styles for women's comfort [6, 7].

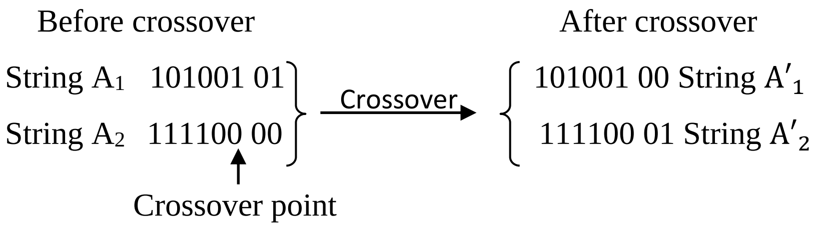
In contrast with these suggestions, seamed problems related to underwear's sewing thread consumption remained irresolvable. Therefore, the amount of sewing thread relative to the underwire and panties is a very significant factor, which depends to many parameters, affects the underwear quality such as size, esthetic, shape, thread tension, the stitch length, the fabric thickness, and its compressive modulus, the seam balance and blend compositions [6, 7, 8]. In contrast with research aiming the consumption of sewing thread relative to woven garments [9, 10], there is no study in the literature survey drawing attention to the consumed thread amount of sewing thread of knitted garments such as underwire bra or panties. Hence, the consumed amount of sewing thread for female lingerie remained untreated by researchers yet excepting some studies regarding bras [2, 11, 12]. In this paper, we draw upon the limited literature on underwear and focus on its consumption of sewing thread.

2. The Genetic Algorithms approach (GA)

Genetic algorithms are a heuristic search and optimization technique which used to optimize complex problem. In fact, it is an algorithm for solving both constrained and unconstrained optimization problems based on a natural election process that mimics biological evolution. The algorithm is composed of three operators: reproduction, crossover and mutation.

2.1. Crossover (Recombination)

The crossover produces new chromosomes in the GA. Like in nature, it allows to mix parental information while passing into the following outline shows the crossover process.



$A'_1$and A'_2: represent part of the new generation descendant.

2.2. Mutation

In natural evolution, the mutation is a random process. It consists to a small change in the genetic string. Besides, in the optimization problem it is equal to a change of the search area in the parameters space. In conclusion, the main steps of genetic algorithm are

- An initial population of N individuals should be generated and produced arbitrarily.
- Apply *"crossover"* and *"mutation"* among individuals to produce next generation.
- Forming the new population of N individuals from the generation of second step.
- Repeating the second and third step until obtaining the suitable individuals satisfying the conditions.

3. The Particular Swarm Optimization (PSO)

Particular Swarm Optimization was proposed by Kennedy and Eberhart [13] in 1995. This method (PSO) applies the concept of social interaction to problem solving. It was developed and it has been applied successfully to a wide variety of search and optimization problems [14, 15]. In PSO, a swarm of n individuals communicates either directly or indirectly with one another search directions (gradients). PSO is a simple but powerful search technique. It takes as a starting point the social behavior of the animals evolving/moving in swarm, such as the clouds of birds and the fish benches. An individual of the swarm has only one local knowledge of his situation in the swarm. He uses this local information, like his own memory, to decide on his displacement. Simple rules, such as "going in the same direction" or "remaining close to its neighbors", are enough to maintain the cohesion of the swarm, and allow the implementation of complex and adaptive collective behaviors. The principle aim of the PSO technique moved away from the too complex behavior of the animals, to preserve only one modeling based on agents simple, called particles. A swarm of particles, which are potential solutions with the problem of optimization, "flies over" the space of research, with the research of the total optimum. According to Talatahari, Sheikholeslami, Farahm and Azar, Daneshpajouh [16], the particle swarm optimization (PSO) involves a number of particles, which are initialized randomly in the space of the design variables. These particles fly through the search space and their positions are updated based on the best positions of individual particles and the best position among all particles in the search space which corresponds to a particle with the smallest weight. The displacement of a particle is based on two types of information: information drawn from its own experiment and information drawn from the experiment from the swarm.

In a space of search for dimension$d$, the particule i of the essaim of swarms is modelled by its vector of position $\vec{X}_i = \left[X_{i1} \quad X_{i2} \quad \ldots \quad X_{id}\right]^T$ and by its vector speed $\vec{V}_i = \left[V_{i1} \quad V_{i2} \quad \ldots \quad V_{id}\right]^T$. The quality of its position is determined by the value of the function objective in this point.

This particle keeps in memory the best position by which it already passed, that one notes $\vec{P}_i = \left[P_{i1} \quad P_{i2} \quad ... \quad P_{id}\right]^T$.The best position reached by its close particles is noted as $\vec{X}_{gbest} = \left[X_{gbest1} \quad X_{gbest2} \quad ... \quad X_{gbest\,n}\right]^T$. The movement of the particles for each iteration is described using equations as follow.

$$\vec{V}_{i,j}(k+1) = w(k)\times\vec{V}_{i,j}(k) + c_1 \otimes \vec{r}_p \otimes (\vec{P}_{i,pbest}(k) - \vec{X}_i(k)) + c_g \otimes \vec{r}_g \otimes (\vec{X}_{gbest}(k) - \vec{X}_i(k))$$

$$\vec{X}_{i,j}(k+1) = \vec{X}_{i,j}(k) + \vec{V}_{i,j}(k+1) \tag{1}$$

Where c_1 and c_g are two constants, called *coefficients of acceleration* $\vec{r}_p, \vec{r}_g$ are two vectors whose parameters are random variables distributed uniformly on the interval$[0\ 1]$. w represents an inertia factor that defines as follows.

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} iter \tag{2}$$

$iter_{\max}$ represents the maximum value of the iterations. $iter$ is the current iteration, $w_{\max}$ and $w_{\min}$ are two positive constants.

The three terms of the equation speed can be translated as follows.

1- $w(k) \times \vec{V}_{i,j}(k)$ represents a physical component of inertia, which encourages each particle to follow its current direction of displacement,

2- The term $c_1 \otimes \vec{r}_p \otimes (\vec{P}_{i,pbest}(k) - \vec{X}_i(k))$ represents a cognitive component, which encourages the particle to return towards the best site than she already visited.

3- The term $c_g \otimes \vec{r}_g \otimes (\vec{X}_{gbest}(k) - \vec{X}_i(k))$ represents a social component, which encourages the particle to move towards the best site found by its congeneric. Once that the displacement of the particles is carried out, the new positions are evaluated and the two vectors $\vec{X}_{i,pbest}$ and $\vec{X}_{gbest}$ is updated, with the iteration $(k+1)$ according to the two following equations.

$$\vec{X}_{i,pbest}(k+1) = \begin{cases} \vec{X}_{i,pbest}(k) & si\ f(\vec{X}_i(k+1)) \geq f(\vec{X}_i(k)) \\ \vec{X}_{i+1}(k) & si\ f(\vec{X}_i(k+1)) \leq f(\vec{X}_i(k)) \end{cases} \tag{3}$$

$$\vec{X}_{gbest}(k+1) = \arg\min f(\vec{X}_i(k+1)) \tag{4}$$

4. Materials and Methods

Openwork structures are used for fancy laces and nets for dress wear, underwear (Figure 1), nightwear, lingerie, sportswear, linings, blouses and shirts, drapes and curtains, and industrial fabrics.

To sew our women's underwear (underwire bras and panties), Table 1 gives the characteristics of sewing thread used. In addition, different synthetic knitted underwear samples (knitting plain structures, blend compositions, thicknesses, etc.) were prepared and 100 mm seam length of each sample was cut and sewn within suitable adjustments requested by the Juki 252-F manufacturer's sewing machine.

Overall, experimental conditions as well as the sewing machine adjustments are kept constant to obtain the similar seamed samples and to guarantee the same experimental conditions for all tested specimens [17, 18]. Besides, for overall studied female underwear is the linear density or count of needle thread (100 %PES) is 24tex and those of looper/bobbin threads are assembled filaments (18tex). The type of sewing thread (twisted or assembled) affects the consumption value [19, 20]. Needle type used is B63 SUK within linear density equals to

Nm70. In addition, to analyse the effect of all studied input parameters, samples were prepared and 100 mm seam length of each sample was cut and sewn within suitable adjustments requested by the Brother 252-F manufacturer's sewing machine. Besides, all combinations were performed, adjusted to the manufacturer's recommended standard settings and repeated 10 times to obtain good sewing quality appearance and to have significant results within a low coefficient of variation (under 5%). Then, the seam was unravelled to get the needle, the bobbin or looper threads consumed in 100mm length. After that, the consumed amount of sewing threads was measured to determine their lengths based on basic stitch types. Table 2 presents the main characteristics of different knitted fabrics used for this analysis.

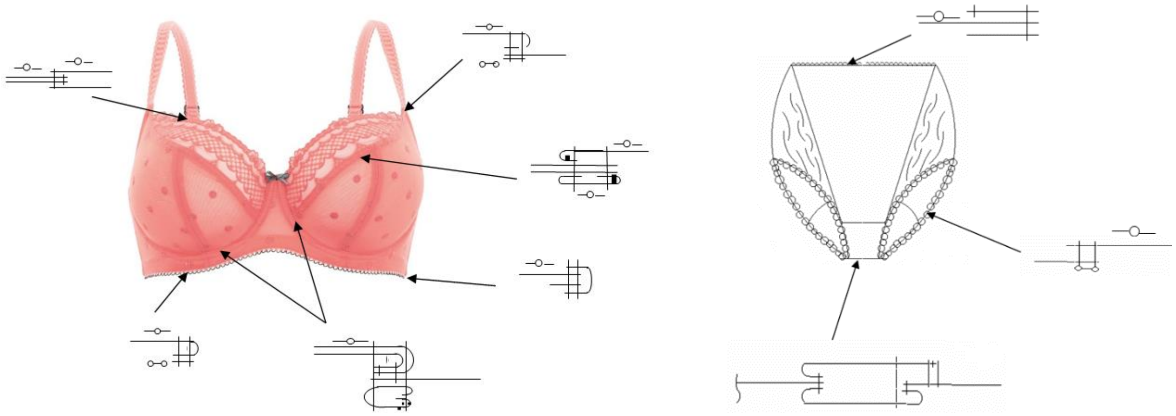

(a) (b)

Figure 1. Bra and briefs made from elastic raschel lace fabric: (a) Women's underwire bra, (b) Female panty.

Table 1. Four sewing thread used and their characteristics.

Characteristics	Sewing Threads			
	1	2	3	4
Structure	Twisted	Twisted	Assembled filaments	Assembled filaments
Number of ends	3	2	-	-
Sense of twist	Z	Z	-	-
Linear density (tex)	24	28	21	18
Composition	70% PES, 30% CO	100% PES	100% PES	100% PES

Table 2. Knitted fabric samples tested and their characteristics.

	Tested knitted fabrics									Norm
Charact.	1	2	3	4	5	6	7	8	9	
Plain structure	*Rib 1x1*	*Tulle*	*Guilloché ordinaire 1 & 1*	*Rib 1x1*	*Double Jersey*	*Jersey + Foam*	*Single Jersey*	*Single Jersey*	*Single Jersey*	-
Blend	76% PAM 24% El	82% PAM 18% El	83.5% PAM 16.5%El	61% PAM 39% El	75% PAM 25% El	85% PAM 15% El	74% PAM 26% El	72.1% PAM 27.9% El	60% PAM 40% El	-
♦*M* (g/m^2) CV%	85 (0.71%)	175.2 (0.28%)	59.33 (1.17%)	198 (0.22%)	465 (0.93%)	328.7 (0.29%)	156 (0.34%)	63.9 (0.20%)	201 (0.41%)	EN 12127
♥T_k(mm) CV%	0.277 (1.76%)	0.429 (0.88%)	0.34 (1.55%)	0.51 (0.74%)	2.5 (0.96%)	3.14 (0.56%)	0.42 (1.44%)	0.46 (1.15%)	0.46 (1.04%)	ISO 5084

♦*M: mass of knitted fabric sample*; ♥*T_h: Thickness of knitted fabric*;- :*No norm standard used*.

For experimental analysis of the consumed thread during sewed underwire and panty samples, some input factors as thickness of knitted fabric (or layer's thickness,F_{th}), underwear's sizes, number of seamed layers, N_l,number of stitches per centimetre, S_L (or density of stitches per seam length) and type of sewing stitch are investigated [9, 10, 20]. Their effects on the consumption behaviours are analysed and discussed deeply [8]. After carefully unstitching the seam accordingly to the French Standard NFG07 101, the consumed sewing threads were evaluated and the mean value of 10 tests within their relative CV% is carried out. Overall samples were conditioned for 24h in standard atmospheric laboratory conditions. Thus, the total sum of threads after unstitching was determined as function of each influential input investigated. Therefore, different sewing machines based on chainstitch/lockstitch were used for stitching knitted fabric samples. Apart from that, Table 3 summarizes the overall studied factors within their levels.

Table 3. Studied parameters and their different levels as function of type of sewing stitch.

Factors	Stitch type		Levels	
			I	II
S_L	301		2.50	7.00
	308		1.50	5.00
	504		3.50	6.00
	512		3.50	6.00
	401		3.50	8.00
	406		3.50	8.00
T_t(N)	301		0.09	1.90
	308		0.07	0.40
	504	T_{nl}	0.10	0.70
		T_{lp}	0.02	0.45
	512	T_{nl}	0.10	0.70
		T_{lp}	0.02	0.45
	401	T_{nl}	0.10	0.49
		T_{lp}	0.14	0.58
	406	T_{nl}	0.07	0.10
		T_{lp}	0.03	0.20
N_l	301		1.00	4.00
	308		1.00	5.00
	504		1.00	4.00
	512		1.00	4.00
	401		1.00	4.00
	406		1.00	5.00
F_{th} (mm)	301		0.27	3.14
	308		0.25	2.50
	504		0.27	2.50
	512		0.27	2.50
	401		0.27	0.46
	406		0.27	0.46

To investigate and analyse each input contribution when level is changed, a Taguchi design was elaborated using Minitab software. Regardless of the analysis, when the level value equals to I, it means the minimum value of the relative parameter. Whereas, the maximum level value is represented by II, if the relative parameter has for example two different levels only. Otherwise, the highest value of level represents the maximum parameter value used to regulate it in the experimentation (see Table 3). The chosen levels, for these studied underwear's, are used to cover maximum investigated women's underwire and panties made by a famous industrial company. Notwithstanding, for female lingerie the overlock, the chain and the cover stitches important classes for functional clothing[19], are classified as the most extensible stitch types, due to high used number of threads during the stitching steps. Because the geometry[21] of the overlock stitch implies more sewing yarn contact with the cloth (the yarn penetrates and surrounds the edge of the fabric), the effect of the raw material will be clearer sewn and facilitates the analysis of the relationship between consumption of sewing thread and characteristics of the fabric sewn [20]. Generally, the majority of assemblies made at the underwearwere sewn gradually with stitch structures based on chainstitch (Class 400), overegged stitch (Class 500), Lockstitch (300). In the present study, the underwire bra and panties are seamed using three-thread overegged type 504, four-thread overegged type 512, chainstitch 401 and 406 and lockstitch types 301 and 308. Consumptions are calculated using different levels of variables according to the Taguchi experimental design. To estimate the coefficients in the general relation between the sewing thread consumption C_{st} and different parameters mentioned above, we followed the forward selection regression procedure. For the analysis of regression, thanks to Minitab 14 software, we calculated the sum of squares due to lack of fit called coefficient of regression according to the method given by Droesbeke et al. and Goupy. The mean sewing thread consumption value, C_{st} expressed in meter, is the amount of thread sewed on women's underwear to assembly plies and different zones of underwire bra and panty.

5. Results and Discussion

The regression technique is used to fit and examine the relationship between the consumed amount behaviors of sewing thread and the four input parameters. These parameters are investigated and are optimized to decrease sufficiently the consumption values to seam women's underwire and panty. Based on overall basic stitch types used to sew these garments, each relative consumption value was optimized and discussed. Therefore, to carry out the consumed sewing length ($\overline{\boldsymbol{C}}_{\boldsymbol{Tot(stitchtype)}}$) in the experimental design of interest, fractional experimental designs type Taguchi, containing height different combinations, were elaborated using Minitab 14 software, according to each stitch type. Hence, linear regression method was used to study the significance of the relationships between all inputs and the tested sewing thread consumption ($\overline{\boldsymbol{C}}_{\boldsymbol{Tot(stitchtype)}}$) behaviour. In addition, it is the first step of optimization and should be completed to test and discuss the effectiveness of the relationships between inputs and output presumed optimized in our specific design of interest[22]. In case of low effectiveness and minimal efficiency of the regression results, the optimization analysis cannot be started because there is no significance between studied databases. To improve the linear regression results, the coefficient of regression value, as well as the analysis of variance, statistical tests were discussed and analyzed.

After having sewed all specimens, we measure the length of thread consumed to join different components of women's underwear. By unstitching, experimentally all knitted fabric samples, the sewed length of thread used is measured. Thanks to Minitab 14 software analysis results, the overall statistical effects on the mean sewing thread consumption values of underwire bra and panty are discussed. The effect of all selected parameters on the thread consumption of studied knitted fabrics (9 samples) to sew women's bras and panties are investigated. By changing level values, the contribution of each influential input parameter can be widely evaluated and deeply discussed. Nevertheless, to improve our results, the regression analysis is conducted and the coefficients of regression values are discussed. All parameter contributions on the sewing thread consumptions are analysed to explain the behaviour of women sewed underwire bra and panty. Keeping the same experimental conditions for all tests, sewed knitted fabrics to made underwear's (underwire bra and panty) using basic stitch types such as lockstitch (type 301 and 308) overegged-stitch (type 504, 512) and chainstitch (type 401 and 406) by varying the factor levels of needle as the tension thread (T_{nl} and/or bobbin, T_{bb} or loopers, T_{lp}), fabric thickness (F_{th}), number of plies or layers (N_l) and density of stitch (or stitch length) are investigated.

5.1. Consumption Behaviour Using Metaheuristic Optimisation Techniques (case of Lockstitch types 301 and 308).

Based on our results, the same evolutions of the sewing consumptions were obtained for the other useful lockstitch types 301 and 308 in female lingerie cases. The variation of consumption behavior as function of studied input parameters is traduced according to the linear regression equations (for each type of stitch) given by Table 4. As proved by many researchers, tension of threads affects enormously the behavior of the consumed amount using sewing machines. Contrary to the rest of factors, the contribution of needle and bobbin threads tensions remained influential on the variation of the consumption behavior of women's underwire bra and panty.

Table 4. Multi-linear regressions of consumption of lockstitch types 301 and 308.

Type	*Equations of regression of consumptions*	R^2
301	$\bar{C}_{st}(cm) = 19.7 - 7.88T_{nl} + 2.56F_{th} + 2.99N_l + 3.71S_L$	97.9%
308	$\bar{C}_{st}\,(cm) = 16 - 36T_{nl} + 7F_{th} + 4.5N_l + 8S_L + 2.5J_{et}$	92.3%

Even though it was realized some relationships, a high significant regression coefficient, R^2 range was eventually found and widely significant (from 92.3% to 97.9%), which seems very close to 1. This high value of R^2 reflects that the needle tension thread (T_{nl}) and/or bobbin tension thread, T_{bb} or loopers, T_{lp}, the fabric thickness (F_{th}), the number of plies or layers ($\boldsymbol{N_l}$) and the density of stitch (or stitch length, S_L)inputs correlate widely with the of $\boldsymbol{\bar{C}_{Tot(301)}}$, and $\boldsymbol{\bar{C}_{Tot(308)}}$. Statistical models of stimulates and explains enough the experimental values.

Hence, for the lockstitch types 301 and 308 respectively, all correlations developed relative to both needle and bobbin thread consumptions are presented in Table 1. Besides, when the same thread for bobbin ($\bar{C}_{bb(301)}$) and needle ($\bar{C}_{nl(301)}$) is used for lockstitch type 301 for example, the sum of the consumed amount length of sewing thread ($\bar{C}_{Tot(301)}$) is also deduced. By changing the lockstitch type, the consumed equation changes for both needle and bobbin as mentioned in the Table 4. However, to improve sufficiently our results, the analysis of variance test should be done. In fact, it helps to classify and evaluate both regression models and the studied parameters. Table 5 shows the analysis of variance and statistical test results.

Table 5. Analysis of variance relative to the consumption behavior for studied lockstitch types.

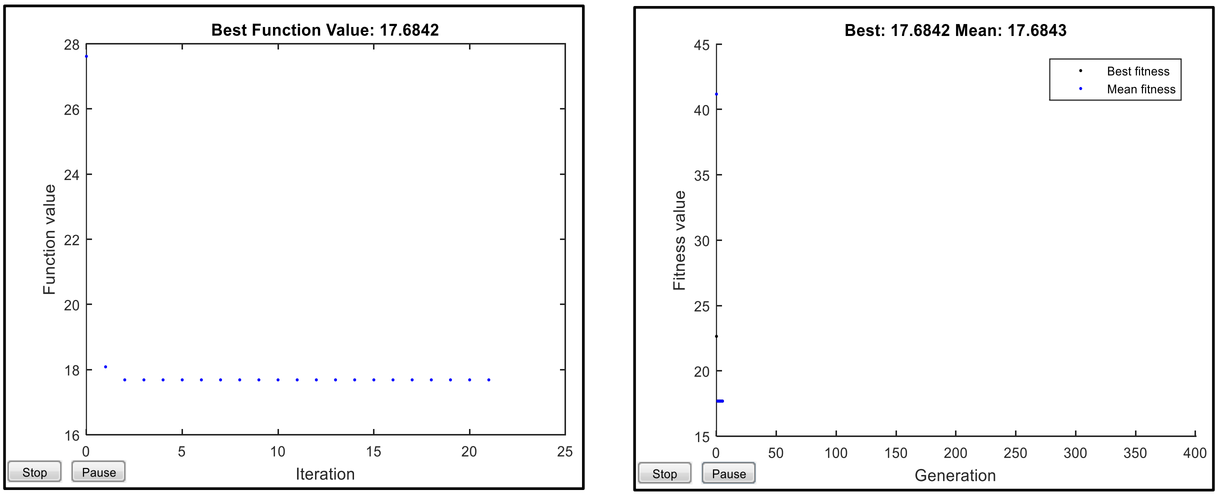
	Lockstitch type 301					Lockstitch type 308				
Source	DF	SS	MS	F	P	DF	SS	MS	F	P
Regression	4	951.6	237.9	34.9	0.008	5	120770	24154	2.2	0.011
Residual error	3	20.5	6.8	-	-	2	22045	11023	-	-
Total	7	972.1	-	-	-	7	142815	-	-	-

According to Table 5, the statistical test was carried out to determine whether the regression model, the linear term, and the quadratic term in this model are significant. The p-statistic was used. It helps to decide whether to reject or fail to reject a null hypothesis (the null hypothesis states that the effect is not significant). In our case the p-value range is from to 0.008 to 0.011 which explain that the regression terms are significant, and the relationship found can be used to prediction and optimization, particularly, in our experimental design of interest. Regarding these results, the generalized findings can be reasonable in this design of interest and have sense.

We proposed to apply the Particular Swarm Optimization (PSO) and the Genetic Algorithms approach (GA) approaches to minimize the consumption of sewing thread for women's underwire bra and panty. Basing on the result of the accurate and significant regression models, using Taguchi experimental design, the optimization of the consumed length can be realized widely. Moreover, the optimization can be also conducted because these regressive models presented significant coefficients of regression, from 92.3% to 97.9%.

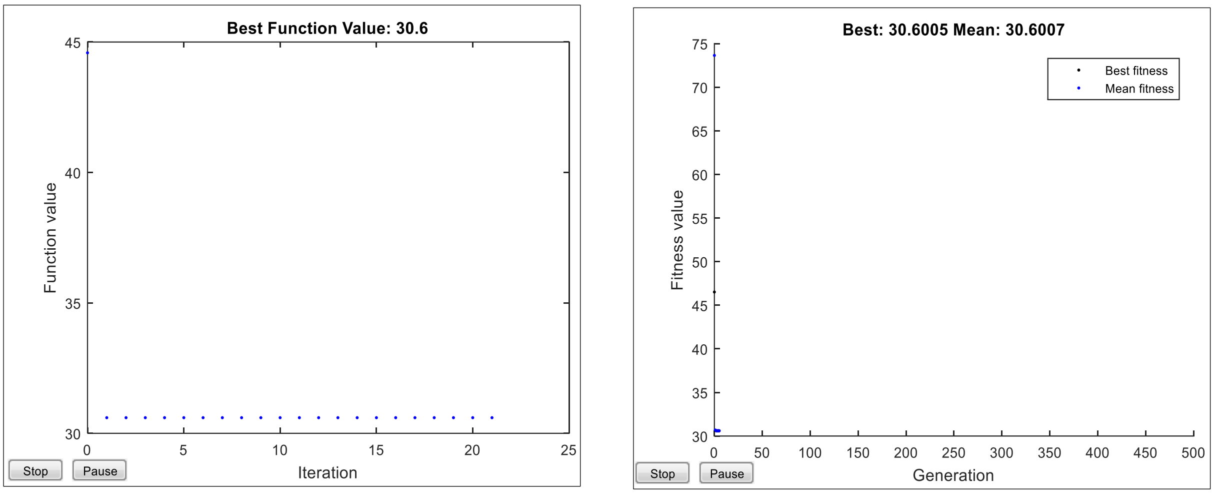
According to our results, 300 ants represent the suitable number given the optimal. Moreover, using this technique of optimization, it may be concluded that after 1000 cycles of randomization, the best value of RKM was occurred which equals 11.4 Kgf.m. Knowing that, the Genetic Algorithm (GA) technique was based on a combination between the different inputs as inspired from both natural generation and mutation, it is not sure to obtain the best bagging behaviour values for the first iteration of the program. According to results, there are five generations, which are recommended by the developed algorithm to optimize the breaking strength RKM. By comparing, the different obtained values, the optimized input parameters as well as the best mechanical properties were saved. However, using the GA approach, the best consumption value corresponding to the optimal inputs is nearest than using PSO method (Figure 2, 3 and 4).

We notice that both PSO and GA methods give very similar results, but compared to GA, the PSO method gives the minimal consumption values within the best input parameters values. Indeed, using PSO algorithms, the optimal consumption value was obtained for the first generation. By comparing the obtained consumption values using the two methods, it may be remarkable that PSO and GA methods give both the best and lowest theoretical sewed thread values for the first running of the program. Moreover, compared to experimental results, PSO both method gives accurate results and help to determine the best consumed thread making up Women's underwire bra and panty. The corresponding optimized input parameters are shown in the Table 6.



(a) (b)

Figure 2. Optimization case of 301: (a) GA, (b) PSO.



(a) (b)

Figure 3. Optimization case of 308: (a) GA, (b) PSO.

Table 6. The optimized input/output parameters using metaheuristic methods for basic lockstitch type 301 and 308.

	T_{nl}	F_{th}	N_l	S_L	J_{et}	$\bar{C}_{stGA}$(cm)	$\bar{C}_{stPSO}$(cm)
301	2.00	2.60	2.00	2.00	-	-	-
	1.90	0.27	1.00	2.50	-	17.6845	-
	1.90	0.27	1.00	2.50	-	-	17.6842
308	2.00	2.00	3.00	2.00	1,5	-	-
	0.40	0.25	1.00	1.50	5.00	-	30.60
	0.40	0.25	1.00	1.50	5.00	30.60	-

Besides, to improve our findings, errors between the experimental consumptions ($\overline{Cst}_{Exp}$) and the metaheuristic values ($\overline{Cst}_{PSO}, \overline{Cst}_{GA}$) are calculated using equations 5 and 6).

Table 7 illustrated all comparative consumptions using metaheuristics within their correspondent errors values ($\overline{Er}_{PSO}(\%)$ and $\overline{Er}_{GA}(\%)$respectively) calculated referring to the formula below.

$$\overline{Er}_{PSO}(\%) = 100 \times \left|\frac{\overline{Cst}_{PSO}-\overline{Cst}_{Exp}}{\overline{Cst}_{Exp}}\right| \tag{5}$$

$$\overline{Er}_{GA}(\%) = 100 \times \left|\frac{\overline{Cst}_{GA}-\overline{Cst}_{Exp}}{\overline{Cst}_{Exp}}\right| \tag{6}$$

Furthermore, the overall comparatives findings given by experimental and metaheuristic (PSO and GA) methods are recapitulated in Table 7. Regarding the results saved in this table, errors calculated using the GA and PSO techniques investigated seem the same, whereas, these techniques gives the same value of the consumed amounts.

Table 7. Comparative values of consumptions basing on experimental, metaheuristic and theoretical methods.

							Comparative C_{st} values using applied metaheuristic methods (m)				
	Optimized input parameters						P.S.O	G.A	Exp.(m)	Error Values (%)	
Stitch type	T_{nl}	F_{th}	N_l	S_L	J_{et}	T_{lp}	$\overline{Cst}_{PSO}$	$\overline{Cst}_{GA}$	$\overline{Cst}_{Exp}$	$\overline{Er}_{PSO}$	$\overline{Er}_{GA}$
301	1.90	0.27	1.00	2.50	-	-	17,6842	17,6845	18,66	5,22	5,22
308	0.40	0.27	1.00	2.50	5.00	-	30 ,60	30 ,60	33,96	9,89	9,89

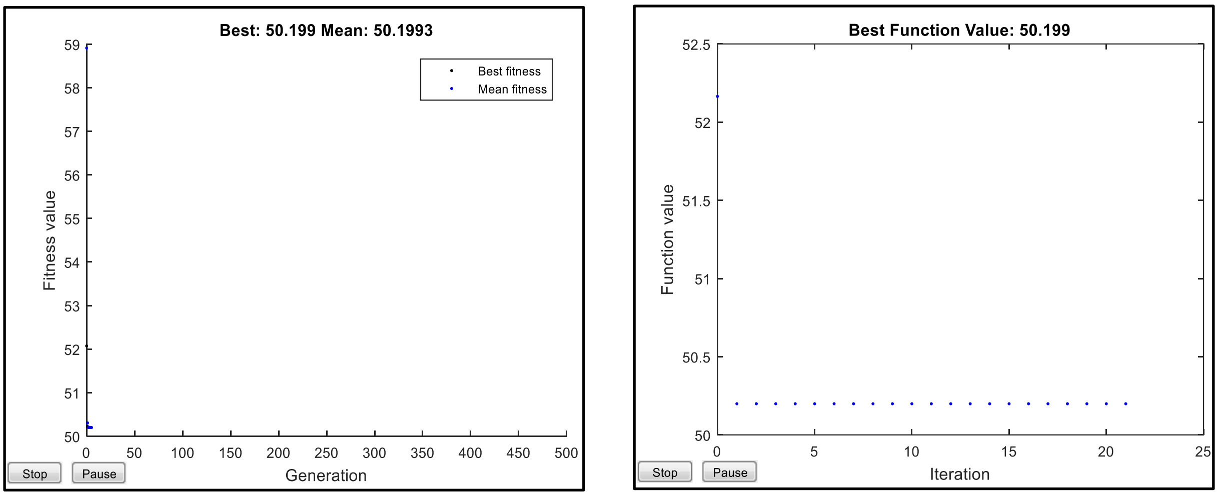
6. Factors' effects on the consumption behaviour, case of Chainstitch types 401 and 406

We adopt the same analysis method as before to analyze the behavior of Chainstitch types 401 and 406. Table 8 presents the relationships between total consumed threads ($\bar{C}_{Tot(401)}$ or $\bar{C}_{Tot\,(406)}$) and the studied factors. To evaluate the consumptions relative to looper(s), $\bar{C}_{lp(401)}$ or $\bar{C}_{lp(406)}$, and needle, $\bar{C}_{nl(401)}$ or $\bar{C}_{nl(406)}$. Equations summarized in Table 8 traduces the effectiveness of the correlations obtained ($R^2 = 95.7\%$and $R^2 = 96.4\%$ for needle thread(s)) and ($R^2 = 73.7\%$ and $R^2 = 80.6\%$ for looper thread(s)).

Table 8. Relationships between consumptions and studied factors within their coefficients of regression.

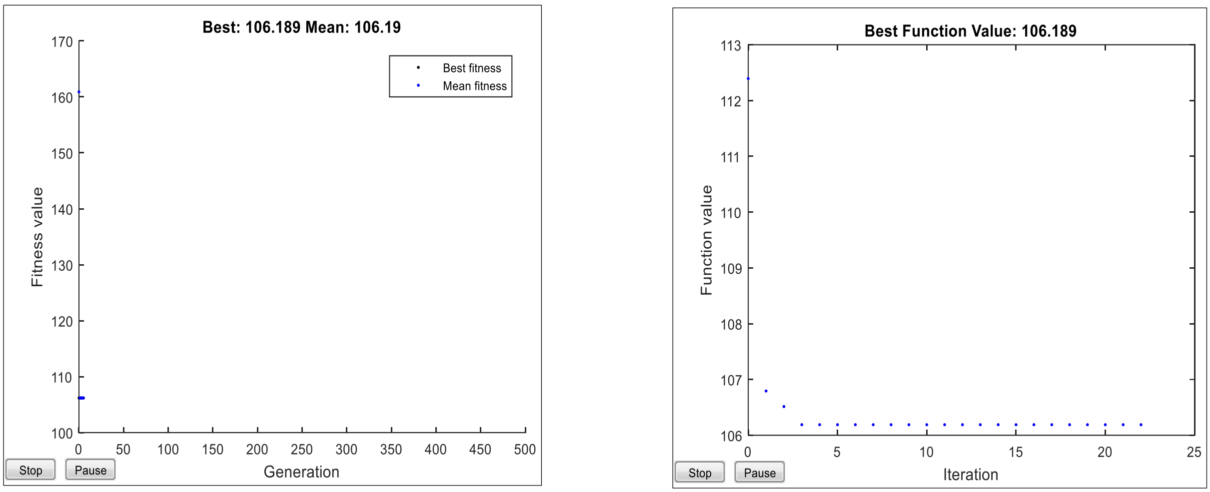
Type	*System*	*Equations of regression*	R^2
401	Needle	$\bar{C}_{nl(401)} = 28.2 + 23.3 \times T_{lp} - 25 \times T_{nl} + 11.7 \times F_{th} + 0.44 \times N_l + 0.91 \times S_L$	95.7%
	Looper	$\bar{C}_{lp\,(401)} = 23.9 - 41.4 \times T_{lp} + 14 \times T_{nl} - 5.9 \times F_{th} + 1.22 \times N_l + 0.74 \times S_L$	73.7%
	Total	$\bar{C}_{Tot(401)} = 25.9 - 20{,}6 \times T_{lp} + 14{,}8 \times T_{nl} - 8{,}0 \times F_{th} + 1{,}33 \times N_l + 0.743 \times S_L$	92%
406	Needle	$\bar{C}_{nl\,(406)} = -4 + 107 \times T_{lp} - 81.2 \times T_{nl} + 132 \times F_{th} + 7.8 \times N_l + 0.91 \times S_L$	96.4%
	Loopers	$\bar{C}_{lp(406)} = 12.6 - 94.8 \times T_{lp} + 12.5 \times T_{nl} + 53 \times F_{th} - 0.3 \times N_l + 10.1 \times S_L$	80.6%
	Total	$\bar{C}_{Tot\,(406)} = 14.3 + 26.9 \times T_{lp} + 17.6 \times T_{nl} + 162 \times F_{th} + 6.56 \times N_l + 11.3 \times S_L$	99.7%

Figures 5 shows the optimized inputs of different levels of factors based on chanistitch type 406 in case of knitted fabrics. Among all evolutions, results report that the consumed amount of sewed fabrics seems lowest with PSO method.



(a) (b)

Figure 4. optimization of 401 chainstitch: (a) GA, (b) PSO.



(a) (b)

Figure 5. optimization of 406 chainstitch: (a) GA, (b) PSO.

In the case of the two types of Chainstitch types 401 and 406, we find the same results as before. Both methods give the same results with the same input parameters. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in this case.

The corresponding optimized input parameters making up Women's underwire bra and panty are shown in the Table 9.

Table 9. The optimized input/output parameters using metaheuristic methods for basic Chainstitch types 401and 406.

	T_{nl}	F_{th}	N_l	S_L	T_{lp}	$\bar{C}_{stGA}$(cm)	$\bar{C}_{stPSO}$(cm)
401	0.10	0.27	2.00	3.50	0.14	-	-
	0.10	0.46	1.00	8.00	0.58	50.1993	-
	0.10	0.46	1.00	8.00	0.58	-	50.1990
406	0.07	0.04	3.00	1.00	0.12		-
	0.07	0.27	1.00	3.50	0.03	106.1890	-
	0.07	0.27	1.00	3.50	0.03	-	106.1890

Table 10 shows the recapitulate findings given by experimental and metaheuristic (PSO and GA). Regarding the results saved in this table, errors calculated using the PSO and GA techniques investigated seem the same, whereas these techniques give values nearest of the consumed amounts. Although the absolute error values calculated using both PSO and GA method is 4.70%.

Table 10. Comparative values of consumptions basing on experimental, metaheuristic and theoretical methods (401 and 406).

							Comparative C_{st} values using applied metaheuristic methods (m)				
	Optimized input parameters						P.S.O	G.A	Exp (m)	Error Values (%)	
Stitch type	T_{nl}	F_{th}	N_l	S_L	J_{et}	T_{lp}	$\overline{Cst}_{PSO}$	$\overline{Cst}_{GA}$	$\overline{Cst}_{Exp}$	$\overline{Er}_{PSO}$	$\overline{Er}_{GA}$
401	0.49	0.27	4.00	8.00	-	0.14	50,1990	50.1993	48,7	3,07	3,07
406	0.07	0.27	1.00	3.50	-	0.03	106,1890	106.1890	101,42	4,70	4,70

7. Factors' effects on the consumption behaviour, case of three and five Overegged stitch types 504 and 512.

We adopt the same analysis method as before to analyze the behavior of three and five Overegged stitch types 504 and 512. Table 11 presents the relationships between total consumed threads ($\bar{\mathrm{C}}_{\mathrm{Tot}(504)}$ or $\bar{\mathrm{C}}_{\mathrm{Tot}\,(512)}$) and the studied factors. To evaluate the consumptions relative to looper(s), $\bar{\mathrm{C}}_{\mathrm{lp}(504)}or\bar{\mathrm{C}}_{\mathrm{lp}(512)}$, and needle, $\bar{\mathrm{C}}_{\mathrm{nl}(504)}$ or$\bar{\mathrm{C}}_{\mathrm{nl}(512)}$, Equations summarized in Table 11 traduces the effectiveness of the correlations obtained ($\mathrm{R}^2 = 95.7\%$ and $\mathrm{R}^2 = 82.6\%$ for needle thread(s)) and ($\mathrm{R}^2 = 73.7\%$ and $\mathrm{R}^2 = 80.6\%$ for looper thread(s)).

Table 11. Relationships between consumed thread amount and the studied factors within their relative coefficients of regression.

Stitch type	System	Equations of regression	R^2
504	Needle	$\bar{C}_{nl(504)} = 85 + 0.4 \times T_{lp} - 85 \times T_{nl} + 1.02 \times F_{th} - 4.6 \times N_l + 1.7 \times S_L$	95.7%
	Looper(s)	$\bar{C}_{lp(504)} = 101 + 1.1 \times T_{lp} - 20 \times T_{nl} + 0.56 \times F_{th} - 2.23 \times N_l - 2.75 \times S_L$	73.7%
	Total	$\bar{C}_{Tot(504)} = 186 + 1.5 \times T_{lp} - 105 \times T_{nl} + 1.58 \times F_{th} - 6.78 \times N_l - 0.62 \times S_L$	87.2%
512	Needle	$\bar{C}_{nl(512)} = 98 + 9.5 \times T_{lp} + 10.6 \times T_{nl} - 14.3 \times F_{th} + 2.9 \times N_l - 10.6 \times S_L$	82.6%
	Looper(s)	$\bar{C}_{lp(512)} = 137 + 2.7 \times T_{lp} + 4.5 \times T_{nl} - 8.1 \times F_{th} + 1.5 \times N_l - 5 \times S_L$	80.6%
	Total	$\bar{C}_{Tot\,(512)} = 235 + 12.2 \times T_{lp} + 15.1 \times T_{nl} - 24.1 \times F_{th} + 3.83 \times N_l - 13.3 \times S_L$	92.7%

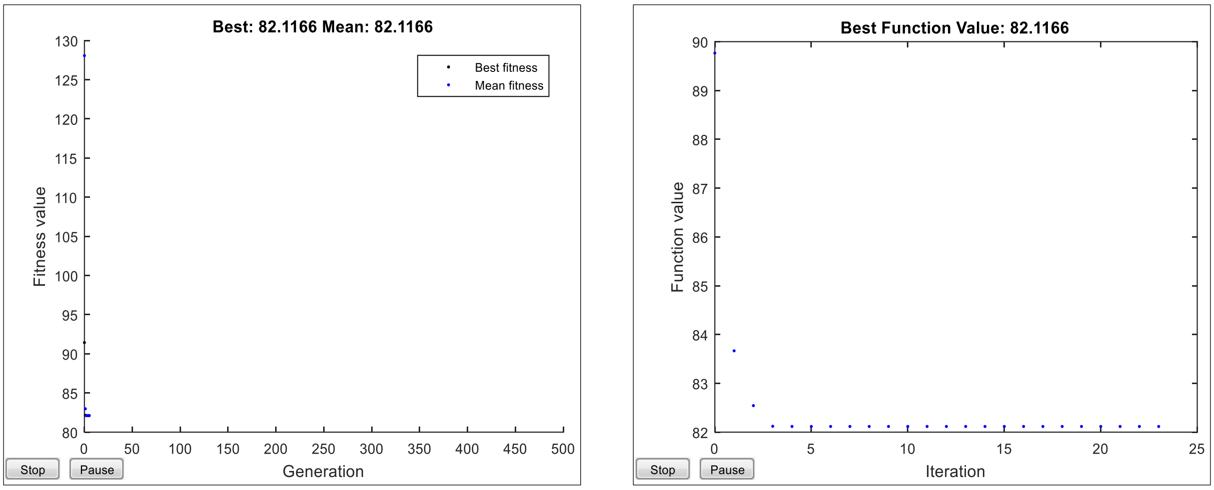
Based on the analysis of variance, the relationships tying consumption of sewing thread based on three, four and five overegged stitch types 504 and 512 were established. Indeed, Table 12 shows the P-value (considered as significant <0.05) of regressive terms on the different equations obtained showing the effectiveness of the significance of factor effects.

Table 12. Analysis of variance results.

Type of stitch	Factors	P-value
Overegged 3 threads type 504	♣C^{st}	0.029
	T_{nl}	0.015
	T_{lp}	0.050
	F_{th}	0.009
	N_l	0.011
	S_L	0.002
Overegged 4 threads type 512	C^{st}	0.018
	T_{nl}	0.012
	T_{lp}	0.040
	F_{th}	0.019
	N_l	0.020
	S_L	0.031

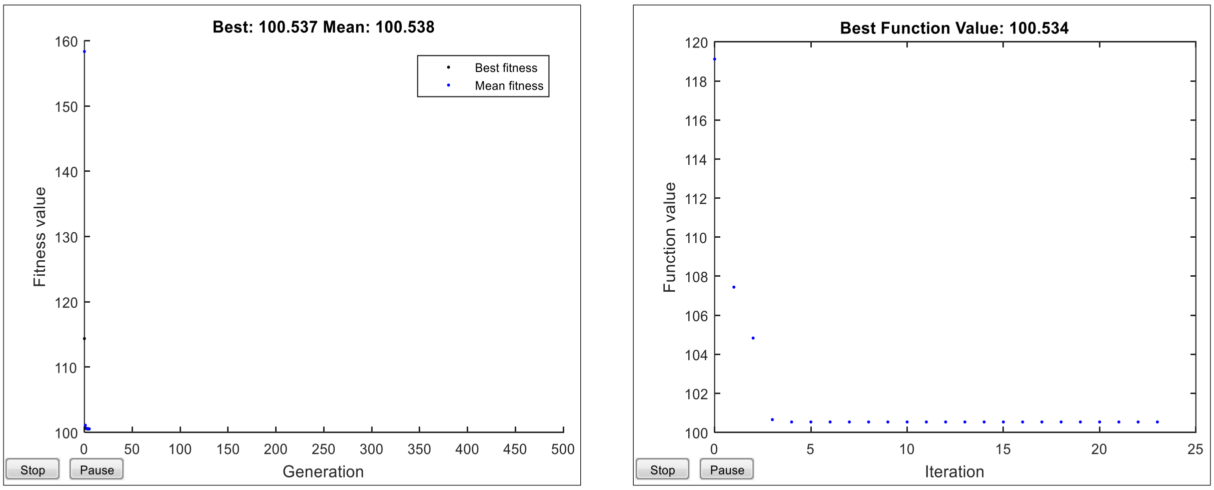
Obtained findings and contributions are improved by the analysis of variance (p-value equals 0.032 and 0.019 for 504 and 512 respectively) and regressive analysis (Table 12) within the investigated coefficients of regression. According to Table 12, the coefficient of regression values is efficient and they are ranged from 73.7% to 95.7%. All these results confirm that the consumption of threads based on tested factors and using overegged stitches can be successfully predicted in the studied experimental design of interest.

Figures 6 and 7 shows the optimized inputs of different levels of factors of three and five Overegged stitch types 504 and 512 in case of knitted fabrics. Among all evolutions, results report that the consumed amount of sewed fabrics seems lowest with PSO method.



(a) (b)

Figure 6. optimization, case of 504: (a) GA, (b) PSO.



(a) (b)

Figure 7. optimization, case of 512. (a: GA; b: PSO).

In the case of the three and five Overegged stitch types 504 and 512, the PSO method gives the minimal consumption values within the best input parameters values. It may be remarkable that PSO methods give both the best and lowest theoretical sewed thread values for the first running of the program.

The corresponding optimized input parameters making up Women's underwire bra and panty are shown in the Table 13.

Table 13. The optimized input/output parameters using metaheuristic methods for basic lockstitch type 504 and 512.

	T_{nl}	F_{th}	N_l	S_L	T_{lp}	$\bar{C}_{stGA}$ (cm)	$\bar{C}_{stPSO}$ (cm)
504	2.0000	1.9600	1.0000	3.5000	0.4100	-	-
	0.7000	0.2700	4.0000	6.0000	0.0200	82.1166	-
	0.7000	0.2700	4.0000	6.0000	0.0200	-	80.1896
512	0.1000	0.2700	2.0000	3.5000	0.4100		-
	0.1000	2.5000	1.0000	6.0000	0.0200	100.5342	-
	0.1000	2.5000	1.0000	6.0000	0.0200	-	99.5340

Table 14 shows the recapitulate findings given by experimental and metaheuristic (PSO and GA). Regarding the results saved in this table, errors calculated using the PSO technique investigated seem lower than those obtained by GA, whereas these techniques gives the lowest values of the consumed amounts.

Table 14. Comparative values of consumptions basing on experimental, metaheuristic and theoretical methods (504 and 512).

							Comparative C_{st} values using applied metaheuristic methods (m)				
	Optimized input parameters						P.S.O	G.A	Exp.(m)	Error Values (%)	
Stitch type	T_{nl}	F_{th}	N_l	S_L	J_{et}	T_{lp}	$\overline{Cst}_{PSO}$	$\overline{Cst}_{GA}$	$\overline{Cst}_{Exp}$	$\overline{Er}_{PSO}$	$\overline{Er}_{GA}$
504	0.7000	0.2700	4.0000	6.0000	0.0200	0.7000	80.1896	82.1166	79.16	1.3%	3.73%
512	0.1000	2.5000	1.0000	6.0000	0.0200	0.1000	99.5340	100.5342	98.72	0.82%	1.83%

Although the nearest absolute error values calculated using both PSO methods (1, 3%) and the GA method (3.73%), the first metaheuristic techniques give the lowest and the best (minimal) consumption value.

To compare all consumptions for different stitch structures, it may be concluded that the consumptions using Particular Swarm Optimization (PSO) method can decrease and predict the consumed thread amount, studied inputs and outputs parameters (Table 15).

Table 15. Comparative consumptions using different method.

Stitch type	$\bar{C}_{stGA}$(cm)	$\bar{C}_{stPSO}$(cm)
301	17.6845	17.6842
308	30.60	30.60
401	50.1993	50.1990
406	106.1890	106.1890
504	82.1166	80.1896
512	100.5342	99.5340

Table 15 shows the studied women's underwire bra in its different sizes. The obtained results show that the variation of the bra sizes (relative to band and bust parts) enormously affects the consumed sewing thread (see Tables 15 and 16). As presented in Table 15, all finding values cover some bra's sizes only, made by industrial company where our analysis was realized.

Table 16. Optimized input parameters.

Stitch type	T_{nl}	F_{th}	N_l	S_L	J_{et}	T_{lp}	EXP	$\bar{C}_{stPSO}$ (cm)	Err PSO (%)
301	1.90	0.27	1.00	2.50	-	-	18,66	17.6842	5,22
308	0.40	0.27	1.00	2.50	5.00	-	33,96	30.60	9,89
401	0.49	0.27	4.00	8.00	-	0.14	48,7	50.1990	3,07
406	0.07	0.27	1.00	3.50	-	0.03	101,42	106.1890	4,70
504	0.7000	0.2700	4.0000	6.0000	-	0.0200	79,16	80.1896	1,3
512	0.1000	2.5000	1.0000	6.0000	-	0.0200	98,72	99.5340	0,82

We called the error as the difference between the theoretical results, $\bar{C}_{st\_th}$ (using the PSO method) and the experimental consumptions,$\bar{C}_{st_exp}$based on stitching and unstitching sewed thread. This difference between theoretical and experimental consumption values as the error value $\bar{E}_{rr}(\%)$ is carried out as function of the input parameters according to following Equation 5.

Using the same expression of error, it can be identified the difference between statistical and experimental consumption for each seaming step of women's underwire bra or panty. This finding encourages industrials to find the suitable predictable consumed thread amounts for women's panties.

Finally, the conceptual bases of the two optimization techniques rest upon two completely different paradigms. The PSO, based upon social swarm behavior, and the GA, based upon genetic encoding and natural selection, have a mutual exclusivity that leaves open the possibility of integrating the two techniques. There have been several attempts at hybridizing these two optimizations. The PSO and GA approaches can be applied in series working like to optimizing the consumed thread of Women's underwire bra and pant. In our case these approaches are used for two reasons. Firstly, result convergence and the effectiveness to the optimized value within the inputs are rapidly obtained. Secondly, the optimized output and input parameters, which not existed between tested combinations in our experimental design, were successfully saved and experimentally improved without applying much iteration.

In fact, selecting the best output and inputs using PSO method needs more program generations (repetitive iteration numbers) although it was considered as the best tool to solve such problems23. Besides, it helps to determine the minimal consumption value but not the lowest compared to the other studied metaheuristic methods such as Genetic Algorithm.

For lowest sizes of women's panties, the consumed amounts of sewing thread are considerable. Although the long schedule of the assembly of underwire bra (29 operations), the consumption values of seamed lowest sizes of women's panties still higher than those relative to largest underwire bra sizes. The short seamed lengths in different parts of the underwire bra can explain this finding in spite of sizes. However, for women's panty, there are large lengths to seam in different parts and consume more sewing threads than underwire bra. In spite of its minimal number of operations to seam women's panty (only 14 steps in our analysis), the total consumed length of thread without wastage equals 1280.1cm for the XS' size of panty.

8. Conclusion

To evaluate the sewing thread consumption for women underwear's, some influential factors are investigated and their contributions on the consumption behavior were discussed and analyzed.

PSO and GA are two relatively recent heuristic search methods. The objective of this research is the application of these two approaches to estimate the consumption of sewing thread. The results showed that although PSO and GA produce on average the same efficiency (quality of the solution). PSO method gives accurate finding values of the consumption within the best combination of input parameters. Therefore, compared to experimental results and regarding the low consumption values obtained, it may be concluded that the both methods give good results except the PSO method is slightly more accurate than the GA method.

The PSO method can widely decrease and predict the consumed thread amount, studied inputs and outputs parameters.

Based on findings obtained the range value of errors enhance the efficiency of predictive results. The results show that the proposed methods are able to achieve the best solution efficiently and easy to implement and helps industrial company of women’s underwear to predict accurately their consumptions and anticipate the quantity of thread to use.

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